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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XXXIX.

SESSION 1874-75.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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OMISSION.

Vol. xxxviii., page 248. The following paragraphs should have appeared:—

It was announced on the 14th of April that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred Robert Daglish, Francis Fox (Sir Chas. Fox and Sons), John Clarke Hawkshaw, M.A., James Shand, Arthur Telford Simpson, James Carrington Simpson, and Henry Hay Wake from the Class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution: Bernard William Cantopher, Harry Polhill Chambers, George Gooch, Everard Lempriere Hesketh, Philip Harrison Holmes, John Harry Lorimer, Henry Charles Snell, and Isidore Spielmann.

ERRATUM.

Vol. xxxix., page 119, line 34, *for* "4 feet 7 inches," *read* "4 feet 1 inch."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1874-75.—PART I.

Sect. I.—MINUTES OF PROCEEDINGS.

November 10, 1874.

THOS. E. HARRISON, President,
in the Chair.

No. 1,398.—"The Nágpúr Waterworks; with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nágpúr; and on the Fluctuation of Rainfall in India and in other places."[1] By Alexander Richardson Binnie, M. Inst. C.E.

Nágpúr, the capital of the Central Provinces of the Indian Empire, is situated in 21° 9′ N. latitude, and 79° 11′ E. longitude, at an elevation of from 975 feet to 1,015 feet above sea level. It is 10 miles distant from the Kanhan river, one of the principal tributaries of the Weingunga, a confluent of the Godavery, and 519 miles N.E. from Bombay, on the Great Indian Peninsula railway, being at the extremity of one of the branches of that line. The geological formation of the district is trappean, with basaltic eruptions rising into low rounded hills, and in some places, as at Sítábaldí, the hill fort of Nágpúr, into abrupt eminences. The city, however, is mostly built on gneiss and other metamorphic rocks, of apparently older formation than the basaltic and trappean series which overlie them. The average annual rainfall for the nineteen years 1854–5 to 1872–3 (Appendix, Table I., page 22) was 40·73 inches. Of this amount 37·52 inches fell during the monsoon months of June, July, August, September, and the early part of October, and the remaining 3·21 inches in showers during the

[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

rest of the year. By the census of 1872, the population was 84,000; and from older records it is believed not to be upon the increase.

Up to the time of the completion of the works about to be described, the inhabitants of the city often suffered severely in consequence of the scanty and impure nature of the water supply. It appears from an official return, made in 1864, that out of twelve hundred and thirty-one wells sunk in the basaltic and metamorphic rocks on which the city is built, about nine hundred yielded brackish water; and even those yielding fresh water are thought to have been contaminated by the main drain of the town. Besides wells, there were two other sources of supply—the Jumá Taláo, an artificial tank or reservoir, between the native town and the civil station (Plate 1, Fig. 1); and an old and decayed work, fed from a reservoir at Ambájharí, 4 miles from the city. The former of these sources was not sufficiently elevated to command the city, and the water was unfit for drinking owing to the drainage area being thickly inhabited; the latter source will be again referred to.

During the dry season following the failure of the rains of 1868, the evils of the then existing state of affairs became painfully apparent. The Chief Commissioner, Mr. J. H. Morris, C.S., having determined to remedy them, the Author was directed to prepare a project for furnishing the city with a pure and abundant supply of water. The question had before been the subject of discussion, and several proposals had been made as to the best direction in which to look for a source of supply. The various suggestions were carefully inquired into, and the whole of the country was examined in detail.

The points to be considered were, as all the streams dry up after the termination of the rains, that a good project must include a large storage reservoir, because the subsoil water, owing to its frequent brackishness, could not be used; that the reservoir should be situated at a sufficiently high level to command the city, and be of such capacity as to provide for years of fluctuating rainfall, and for periods of more than one year during which it might remain below the average; and that the reservoir should receive the drainage of a tract of country large enough to yield, even under the average rainfall of the three driest consecutive years, a sufficient supply for the wants of the city, and to provide for evaporation during the dry months.

The result of this examination led the Author, in November 1869, to advise that the old reservoir at Ambájharí should be remodelled and enlarged, and that the water should be brought to the city in cast-iron pipes under constant pressure. These

recommendations, having been approved by the municipality and the local officers, received the sanction of the Government of India in April 1870.

The old works, which formed the basis of the project, were constructed under the Bhonslá dynasty (Rajhas of Nágpúr), about eighty or ninety years ago, principally for the purpose of supplying the palace, and the houses and gardens of a few of the native gentlemen attached to the Court. The site of the reservoir is at a point on the river Nág, which flows through and gives its name to Nágpúr, a little to the south-west of the village of Ambájharí (Plate 1, Fig. 1), which name literally means the spring of the mango grove. Perhaps the existence of some natural springs at this place may have led to the selection of the site; at any rate, the Author can state, from personal observation, that even when there was no water in the old reservoir, springs did exist in the low ground below the embankment, and provision appears to have been made for securing the water flowing from them, when other sources of supply failed.

The ancient reservoir was formed by an embankment, rather crooked in its alignment, and 856 yards in length (Plate 1, Fig. 2), across the valley of the Nág. Its average height was 12 feet, the extreme height being 20 feet. Its width at the top varied from 40 feet to 60 feet, and the back slope had an inclination of about $1\frac{3}{4}$ to 1; the inner face was protected by a vertical rubble wall, with projecting semicircular and octagonal bastions, also of rubble masonry. The reservoir, when full, had an area of 237 acres, and contained 80,000,000 cubic feet. The water was drawn from it through a masonry sluice, the flood waters being discharged over two waste weirs, of the aggregate length of 128 feet. Another sluice, 200 feet south of the one in work, had been stopped up, but a good deal of water leaked through.

The Ambájharí reservoir was dry during April and May 1869. The Author then examined the face wall, which was cracked in many places, and showed other signs of unequal settlement, and at the same time tested, by digging holes in the bed of the reservoir, the amount and nature of the deposit since its construction. This was clean earthy matter, in no case of a greater depth than 2 feet 6 inches. The old sluice (Plate 1, Figs. 3 and 4) projected several feet beyond the face wall, and was flanked on the sides by stone steps. The discharge of water was regulated by wooden plugs inserted in five holes in the steps of the outer face, and in seven holes in the side of the well or chamber A. The flow into the city through the masonry pipe was further regulated by another series of wooden

plugs in the chamber C; and the water could at any time be cut off from the city by inserting one plug in the outlet of the well marked B. The sluice was generally worked by opening the upper submerged plug on the outside, so as to keep the water in the well A a few feet lower than that in the reservoir as well as one of the submerged plugs in the well A, so that the water did not rise more than a foot or so in the well B; and this arrangement was repeated in the well or chamber C. In the south side of chamber C there was another opening, for the purpose, as explained by one of the old native watermen, of collecting the water from the springs below the reservoir, which often flowed, even in dry seasons, when the reservoir was empty; but in 1869 the channel leading to it was choked.

The pipe from the chamber C to the city was 4 miles in length, and was formed of blocks of sandstone, from 2 feet 6 inches to 3 feet 6 inches long, and 18 inches to 2 feet square, through which a circular hole 9 inches in diameter was bored (Plate 1, Figs. 5 and 6). At one end of each block there was a recess and at the other end a projection, and the joints were made good with mortar, in which a little chopped hemp or cotton had been mixed; the whole of the blocks were surrounded by basalt rubble masonry to a thickness of from 1 foot to 18 inches. The alignment and levels of the pipe track were somewhat irregular. Frequent water towers or cisterns allowed of the disengagement of air, but their principal use was to reduce the head of water, which escaped when required, by openings in the sides of the tower, closed by wooden or masonry plugs. In this way the available head to overcome friction in the last 3 miles of the pipe was reduced to 1 foot. The distribution in the city was on the intermittent principle, the water from the reservoir being delivered into small cisterns (Plate 1, Figs. 7 and 8), in the bottom of which were several holes leading to the service pipes of unglazed earthenware. The water was in turn admitted to or shut off from these pipes by the insertion of wooden plugs in the holes. The design of these old works exhibited much care and skill, principally with a view to accommodate the pressure of the water to the strength of the pipe.

In 1868–69 the whole of the earthen part of the embankment and of its slopes was covered with trees and bushes, and the water leaked in many places from the toe of the outer slope. This leakage, joining with the flow of the springs, had caused a swamp just below the bank, which was covered with rank vegetation, and was dangerous to walk or ride over, being full of holes and boggy places. Trial pits having been sunk outside the embank-

ment, it was found that the rock floor of the valley was covered to a depth of from 3 feet to 14 feet with sand, gravel, and other more or less porous material; and it was evident that the water made its way from the reservoir under the embankment, as it rose in, and flowed out of, these trial pits in considerable volume. The masonry pipe was also in a ruinous condition; the soft sandstone had been broken and repaired in many places, and had become very friable; a bright green vegetation flourished around the leaky places; and internally the pipe was choked by weeds brought down in the water when the reservoir was low, and by the roots of trees. Hence, owing to leakage, both surface and subsoil, and to the evaporation to which so shallow a sheet of water was exposed, the reservoir, as in 1869, was occasionally dry during the hot months, when water was most required; and even when the reservoir was full, the old stone pipe could deliver but a small supply in the city, and this was continually shut off to effect repairs, &c.

The Author selected these old works because above the reservoir there was a catchment area of 6·6 square miles (Plate 1, Fig. 1), free from cultivation and but slightly covered with soil, the geological formation being nodular trap and other associated basaltic rocks. The site of the ancient reservoir also afforded the most economical storage ground, and its level and distance from the city were such as to enable gravitation works to be constructed within the means at the disposal of the municipality.

The works consist of:—A puddle trench through the old embankment, extending at least 3 feet into the rocky floor of the valley. The embankment has been raised 17 feet 4 inches above the level of the top of the old face wall, and a puddle wall constructed to within 3 feet of the full height of the new embankment. Inside the reservoir a straining and regulating tower has been built, and a syphon discharge pipe laid from it over the top of the old embankment, and below the level of the newly raised portion, with a valve house at the foot of the outer slope. A new waste weir at a level 13 feet 4 inches above those of the old reservoir, and a main pipe 4 miles long and 13 inches diameter, with 10,500 lineal yards of distribution pipes of 12 inches diameter, and downwards, have also been provided. The result is that a reservoir, containing a gross quantity of 257,500,000 cubic feet of water, and an available storage of 240,000,000 cubic feet, or 1,500,000,000 gallons, has been formed, the top water area of which is 370 acres. It is calculated that, with this amount of storage, a supply of 15 gallons per head per day of twenty-four hours can be maintained even in years of extreme drought.

While the works were being carried out the water was retained in the old reservoir to keep up, as long as practicable, a supply through the old stone pipe. Active operations were commenced in October 1870, by draining the swamp below the embankment, followed by the excavation of the puddle trench. It was determined to sink the trench at a distance of 45 feet 6 inches from, and nearly parallel to, the old face wall; by so doing the trench was carried through nearly the whole depth of the embankment, and, for the most part, a good foundation of well-consolidated material was secured for the front, and the greater part of the back slope. The removal of the necessary material, which was of inferior quality, allowed of its place being filled up on each side of the puddle wall with selected earth. This trench (Plate 1, Fig. 9) had side slopes varying from $\frac{1}{4}$ to $\frac{1}{2}$ to 1, up which steps were cut, by which the coolies carried basket-loads of earth, either to form the slope of 2 to 1 in front of the face wall, or the base of the outer slope where it extended beyond the embankment. While the excavation was in progress the water in the old reservoir stood from 15 feet to 20 feet above the deeper portions of the excavation, the leakage being pumped out by a portable engine and centrifugal pump. In cutting the trench, as the rock was approached, several springs of considerable volume were intercepted at, and a little to the north of, the two square depressions in the floor of the puddle trench (Plate 1, Fig. 2), 1,000 feet from the south end of the embankment. The water in these springs came from the outer side of the trench, and probably was the subsoil drainage of high land to the south-east of the southern end of the embankment; for, when this part of the trench was filled with puddle, the springs below the embankment increased, although it was towards the end of the hot season. The trench was 1,033 yards in length, of an average depth of 25 feet, and an extreme depth of 36 feet near the old sluice. The bottom width in the rock was 5 feet, the top varied from 20 feet to 49 feet. The quantity of material excavated was, in the old embankment, 965,718 cubic feet; in the ground below the old embankment and above the rock 243,788 cubic feet, and in the rock itself 58,970 cubic feet, making a total of 1,268,476 cubic feet, or about 47,000 cubic yards. The cost, including blasting, pumping, and preliminary drainage, was 23,681 rupees, or at the rate of a fraction over 1*s.* per cubic yard.

The puddle wall, filling the trench, and forming the centre of the embankment, was constructed with clay, spread in even layers not exceeding 8 inches in thickness, soaked in water during the night, and worked up in the early part of the following day.

There being no good clay procurable in the immediate neighbourhood of the works, it was brought from a distance of 3 miles in bullock carts. The width of the puddle wall (Plate 1, Fig. 9) at the top is 5 feet, with a batter on each side of 1 inch per foot; this makes the thickness at the ground level about 10 feet. It decreases from that width down to 5 feet in the rock at the bottom of the trench. The consumption of puddle was 900,000 cubic feet, or 33,300 cubic yards, and, as it cost 66,586 rupees, the work was executed at a rate of 4*s.* per cubic yard, including digging, carting, and working. The earth from the puddle trench was placed in front of the face wall at a slope of 2 to 1 (Plate 1, Fig. 9). The berm on the top of the old embankment, to prevent the face wall becoming surcharged, is 9 feet 6 inches wide, and is raised 2 feet 4 inches above the old wall. The top of the ancient embankment has been carefully trenched longitudinally to insure a junction between the old and the new work. The general inclination of the inner slope is $2\frac{1}{2}$ to 1, that of the outer slope being 2 to 1. The top of the embankment is 6 feet above the sill of the waste weir, and has an extreme width of 7 feet 6 inches, being finished off with curbs of rough stone laid dry. Black cotton soil was placed on each side of the puddle wall in the trench, and was raised above the level of the old bank at a slope of 1 to 1, the outer portion of the embankment being the harder and less retentive material. The earth was deposited by coolies from baskets in layers about 1 foot thick, each layer being watered, trodden, and punned, before the next was laid on. The inner slope is pitched with hard stone 1 foot thick; the outer slope is turfed, the berm, or road, at its foot being composed of stones, trap rock, and gravel.

The total cost of thus raising the embankment was 42,774 rupees; there are about 2,900,000 cubic feet, or 107,407 cubic yards of earthwork, which cost on an average $5\frac{1}{2}$ pence per cubic yard. The rates for the pitching varied from 5*s.* to 10*s.* per 100 superficial feet, and for the turfing 2*s.* per 100 superficial feet.

The reservoir was full in October 1872, nearly so in 1873, and 1·3 foot of water flowed over the waste weir in August 1874. Three monsoon seasons have passed, and, with the exception of a slip of earth from the back slope, in September 1872, which was soon repaired, all has gone well. This slip may be attributed to the new earthwork parting from the old slope, possibly caused by the boggy ground at the toe of the slope.

It was not considered prudent to break through or interfere with the continuity of the face wall, or to run the risk of

laying the discharge pipe under the full height of the embankment; and as a tunnel round the end would have been expensive, owing to the flat slopes of the valley (Plate 1, Fig. 10), it was at last determined to bring the pipe over the top of the face wall, using the masonry in the old sluice as a partial support.

The outlet finally adopted was a straining and regulating tower (Plate 2, Figs. 1, 2, and 3), about 30 feet from the face of the sluice inside the reservoir. The excavation for the tower was made within an earthen embankment run out from the old face wall, the inner toe being supported by piles and planking. It was carried down to the rock 12 feet below the former bed of the reservoir, and 18 feet below the water level; and when the masonry rose above the top the temporary earthen dam was removed. The internal dimensions of the tower are 15 feet by 6 feet; up to the former ground level it is of basalt rubble, the space between the walls being filled with concrete; above that level it is of sandstone ashlar, with the upper part and the arching set in Portland cement. The face most distant from the embankment (Plate 2, Fig. 1) is pierced by three openings 2 feet square fitted with cast-iron sluice doors, moved by cross-heads and screws, placed in the three pillars resting on a cast-iron girder at the top of the tower; by these sluices the water can be drawn from near the surface.

Sliding in three grooves in the inside of the tower are six straining frames, carrying copper-wire gauze strainers of thirty meshes to the inch; and outside the three square sluices the water passes through a $\frac{5}{8}$-inch wire netting supported on iron cross-bars. The upper part of this tower is partly arched over so as to give an area of 286 superficial feet for convenience in lifting the strainers working the sluices, &c. The openings between the arching are covered with removable planking.

A foot bridge of wrought iron, 81 feet long and 3 feet 6 inches deep, supported in the centre by an ashlar masonry pier, extends from the top of the embankment to the tower.

The syphon commences at the bottom of the tower. It is 2 feet in diameter, 184 feet long, and from 1 inch to $1\frac{1}{2}$ inch in thickness. The lip is 31 feet from the top of the coping, and the inner end is commanded by a sluice valve, the spindle of which is prolonged upwards and terminates in a cast-iron pillar on the top of the tower, from which it can be worked. Between the straining tower and the masonry of the old sluice the pipe is carried on a semi-arch of rubble masonry, abutting at one end against the rock and the foundation of the tower, and at the

other end against the old sluice into which it is built. The width of this arch is 4 feet, and its upper surface is in steps faced with sandstone ashlar; on these steps ashlar blocks, 1 foot wide, carry the syphon, which is also inclosed in rubble masonry.

The wells (A and B) of the old sluice having been filled with concrete, and the openings in them built up, the pipe is borne partly on sandstone blocks, and partly on concrete and the masonry of the old sluice. Walls of rubble masonry are so built across the pipe as to allow of the flanged joints being surrounded with puddle, and the remainder of the pipe with concrete.

The pipe passes through an arched opening in the pier which supports the foot bridge, and where it crosses the puddle trench it rests on a masonry pillar, which also carries the end of the foot bridge; on the outside of the puddle wall it is supported on the foundations of the charging well. Between the well, B, of the old sluice and the support pillar of the bridge, the pipe is carried over the opening of 16 feet on sandstone blocks resting on two wrought-iron rolled beams 1 foot deep, rivetted together. Between the pillar and the charging well the large pipe, 14 feet in length, rests, for the distance of 10 feet spanning the main puddle trench, on stone blocks supported on two wrought-iron girders 8 inches deep. Down the back slope of the embankment the syphon is sustained on a semi-arch of concrete 5 feet in width, on the steps formed in the top of which are sandstone blocks, 1 foot wide, which support the pipe. Cross walls are also provided, with puddle round the joints and concrete covering the remainder of the pipe. At its lower end the pipe is curved vertically upwards and covered with a semispherical cover, carrying one of Bateman and Moore's 8-inch air valves—an arrangement to prevent air from the main pipe entering the syphon and discharging it. The outer end of the syphon terminates in a valve house, in which are inclosed the air valve and two valves, 15 inches in diameter, placed on a branch which projects at right angles from the syphon. One of these valves governs the supply to the city, the other is arranged for scouring out the straining tower and syphon, or for giving off surplus storage water for irrigation.

The crest of the syphon is in the charging well, and at that point the pipe is provided with a branch 4 inches in diameter. This branch is closed by two valves with a gauge glass between them; the upper end of the branch having a funnel mouthpiece for charging the syphon, when the terminal valves are closed.

The flanged joints of the pipe (Plate 2, Figs. 4 and 5) are secured by eight bolts. A conical projection of 2 inches, carrying an

india-rubber rope washer, fits against a recessed shoulder in the corresponding opposite pipe; the faces of the flanges are also provided with flat india-rubber washers $\frac{1}{8}$ inch thick, and a turned projection and recess in the corresponding flanges. The joints were made good with red-lead and oil; and the thickness of the india-rubber washer between the flanges outside, and any small openings round the bolt holes, as well as inside the pipe at the point of junction, were caulked with iron rust joint cement, after which the whole of the outside of the joint was covered with Portland cement before it was surrounded with the puddle.

Where the pipe crosses the puddle in the trench, great care was taken to bed it firmly. The puddle was allowed to settle after it had been worked up during one whole monsoon and cold season, say for eight months; it was then consolidated by repeated blows from a monkey weighing 10 cwt., and beds were cut in it to receive the girders. These were filled with well-rammed puddle to prevent water passing along them, and their ends were set in neatly-fitting sandstone chairs run in with Portland cement. For a few feet above, and on each side of the pipe, the puddle was worked up softer than usual to prevent its clinging to the pipe.

The lift of the syphon, from the sill of the lowest sluice in the straining tower to its crest in the charging well, is 14·55 feet; and as the water in the reservoir will never be drawn lower than 5 feet above that level, the syphon will not be required to lift more than 9·55 feet, and at this level the valves in the valve house would be 5·2 feet under the surface of the water.

The total cost of the outlet, including the straining tower, foot bridge, charging well, and valve house, was 28,935 rupees. The rates were, for ashlar from 1*s.* to 2*s.* per cubic foot, for basalt rubble from 10*s.* to 16*s.* per cubic yard, and for concrete 8*s.* per cubic yard. The cast-iron sluices, valves, &c., were obtained under a lump contract.

The new waste weir (Plate 2, Figs. 6 and 7) consists of a curved wall, 200 feet long by 3 feet thick, capped with ashlar, protected on each side by training walls 120 feet in length. The water flows over the weir into a rock cutting, which for the first 150 feet has a fall of 1 in 45, converging from 150 feet to 60 feet in width; from thence the inclination increases up to 1 in 40. The sides of this cutting being rocky, little masonry was required, and the cost was only 8,214 rupees.

The main and city distribution pipes work under an average head, when the reservoir stands at low water, of from 30 feet to 60 feet. As there are few high houses in Nágpúr, this pressure is

considered sufficient, and all the water is supplied on the ground level. The service is almost entirely a public one, the water being given off from self-closing standards, at intervals of about 100 yards along the streets, only a few houses being as yet supplied with private taps or cisterns. Fire-cock air valves are also placed at every 100 yards apart.

The cast-iron piping was supplied by Messrs. R. Maclaren and Co., of Glasgow, at rates of 70 rupees 12 annas to 72 rupees 8 annas per ton delivered in Bombay; but the railway carriage raised the cost to an average of nearly 117 rupees delivered in Nágpúr. The contract for the pipes was signed in Nágpúr on the 1st of February, 1871, and the first consignment was received on the 15th of the following July, it having been shipped *viâ* the Cape of Good Hope.

The total cost of the works, including engineering expenses, a bungalow at the reservoir for the engineer in charge, and a road 2½ miles in length to Nágpúr, was 395,320 rupees, or say £40,000, representing a rate of 9*s.* 5*d.* per head, or £31,500 per million gallons supplied per day. This does not, however, give a perfectly correct idea of the cost, as a portion of the embankment previously existed, and about 10,000 yards of additional distribution pipes are still required to bring the supply up to a European standard.

The work was executed under the Author's supervision, partly by petty contractors, partly by day labourers; many prisoners were also employed, the jail authorities being paid for their labour by piece-work, at the rates accepted by the petty contractors.

The Intensity of Rainfall and the Proportion flowing from the Ground as observed at Nágpúr.

Although the general fluctuation of rainfall in India is similar to that in other parts of the world, yet it has certain well-marked peculiarities. The first of these is, that the greater part of the annual rainfall is confined to a few months during the south-west or north-east monsoons; secondly, that the greater part of the year is almost rainless, and thirdly, that during the wet months the rainfall is much more intense than in temperate countries. To take two well-known cases on record, a fall of 23½ inches in twenty-four hours has been measured at Madras, and on another occasion a depth of 14 inches in twenty-four hours was gauged at Bombay.

In the Appendix, Table II., page 23, gives the details of certain extraordinary showers which came under the Author's observation

at Nágpúr during the monsoon of 1872. The showers range from 0·5 inch in depth up to 3·92 inches, and the rate of fall or intensity from 0·163 inch to 4·733 inches per hour. The rainfall, noted in Table II., is the average of three gauges placed within the catchment area of the Ambájharí reservoir. The quantity of water discharged from the area of 4,224 acres was measured by noting the amount and the time of rise of the water in the reservoir. These showers produced a flow varying from almost nothing, in the case of the shower of 2·24 inches in one hour and twenty minutes on the 18th of June, up to a discharge of 33,160,380 cubic feet due to a fall of 2·2 inches in one hour and twenty minutes on the 16th of September. These facts prove to what an extreme state of dryness the soil in India is reduced at the end of the hot season, and how saturated it becomes after heavy rain later on in the monsoon. In the last column of Table II. is given the proportion of the rainfall of the various showers which flowed from the ground in the times noted in column 6. From this it will be seen that, of the 2·2 inches on the 16th of September, 98 per cent. entered the reservoir within two hours and fifty minutes.

The consideration of the above remarks naturally leads to the question, What percentage of the total annual rainfall flows from the ground and can be impounded? Almost every drainage area has, in this respect, peculiarities proper to itself, but the Author will confine his remarks to the facts observed at Nágpúr; and as there are two peculiarities which he thinks will be found common to most cases in India, he wishes first to invite attention to them.

It will be noticed in Table I. that the average annual rainfall at Nágpúr is 40·73 inches, of which 37·52 inches fall in the monsoon, and 3·21 inches in the dry season. But no dependence can be placed upon this latter quantity as a means of water supply, for careful observations have failed to detect any part as flowing from the ground into the reservoir. And, secondly, to such a state of dryness is the ground reduced in the commencement of June, that a large portion of the first showers of the monsoon are either absorbed or evaporated, and but a small portion flows from the ground. The consequence is that the records of the discharge of the drainage area are confined to about four months, and when plotted form a curve, owing to the proportion which is discharged, commencing at zero at the beginning of the monsoon and gradually increasing as the rains continue. These facts render the study of the subject much more simple for Nágpúr than for places in England; because the observations of each year commence under

the same circumstances, and as it were from a common datum or point of departure.

The observations on the discharge of the Ambájharí drainage area (Plate 3) extend over the monsoon months of the years 1869 and 1872. Commencing with 1869, from the 17th of June to the 31st of July a depth of 12·76 inches of rain was gauged; the quantity of water that flowed from the ground, being about 19,600,000 cubic feet, showed that only 1·25 inch had passed off, which gives about 90 per cent. as either evaporated or absorbed. The rainfall for August was 9·61 inches, of which the proportion discharged was 35 per cent., and for September it was 7·41 inches, of which 44 per cent. flowed from the ground. Up to the end of each month the total effects were—June and July as above quoted; June, July, and August, 22·37 inches of rain, and a discharge of 20 per cent.; up to the end of September, 29·79 inches of rain, and a discharge of 26·8 per cent. In 1872 the proportions were, for 6·77 inches in June the amount discharged was 4·7 per cent.; for 12·70 inches in July, 22·7 per cent.; for 11·82 inches in August, 55·8 per cent.; for 7·99 inches in September, 74·4 per cent.; and after an interval of dry weather, for the 4·37 inches in October, 39·4 per cent.

The result was that the total discharge increased as follows: for June 4·7 per cent.; up to the end of July 16 per cent.; up to the end of August 31 per cent.; up to the end of September 40 per cent.; and at the end of October it still remained at 40 per cent. In Plate 3 the horizontal measurements represent inches of rainfall, and the vertical ones the percentage which flowed from the ground into the reservoir. Hence it can be ascertained what the discharge of the drainage area will probably be for different depths of rainfall, as the proportion absorbed will depend, all other circumstances being equal, on the depth of the rainfall. Thus, for an average season's fall, or 37·52 inches, 38 per cent. may be expected, or 14·25 inches, equal to 217,120,000 cubic feet. In a season the fall of which was that of the average of the three driest consecutive years, or 30 inches, the discharge would be about 28 per cent., or say 8·4 inches. This would yield 128,000,000 cubic feet, and in a year such as 1868, the driest on record, when the amount was 19·28 inches, about 15·5 per cent., or 3 inches would flow from the ground and yield only 46,000,000 cubic feet. These calculations deal only with the flow from the drainage area. But the actual quantity of water that can each year, without fail, be utilised, depends not only upon the fluctuation of the rainfall, and the proportion which flows off the

ground, but also upon the capacity of the reservoir to store and modify the fluctuations.

To render this matter as clear as possible, the Author has worked out, from the diagrams (Plate 3) and a revised twenty-years' record of rainfall, Table III. (page 24), which shows what proportion of each year's fall would in all probability have flowed off the ground, and also the actual depth in inches and quantity in cubic feet discharged in former years. Taking this as a basis of calculation, nine different cases have been assumed of reservoirs with varying capacities, affording different amounts of annual supply. Each case has been carefully tabulated on the common system of supply and demand, to indicate what amounts of the water flowing off the drainage area could be used, or how much would be wasted; and also what would be the minimum storage in the reservoir at any time during the twenty years under review. The results of these calculations are given in Table IV. Tables III. and IV. show that the proportions between the average, maximum, minimum, and the three consecutive driest years' rainfall do not correspond with the equivalent proportions in the yield of the drainage area. Thus the minimum rainfall is 52 per cent. of the average, while the minimum yield of the drainage area is only 23 per cent. of its average yield. In the same way the yield of 37 inches, an average year's fall, would be 38 per cent., and give 215,280,000 cubic feet; but the average yield of the drainage area is only 204,520,000 cubic feet. This matter requires attention, as the working out of Table IV. will show, where the storage and the supply are given in terms both of the rainfall and of the yield of the drainage area.

It will be seen from Table IV. that the present reservoir, with a capacity of 240,000,000 cubic feet, can store 117 per cent. of the average yield, or 106 per cent. of the average rainfall; and that it can supply from 120,000,000 to 140,000,000 cubic feet per annum, which represents from 58 per cent. to 68 per cent. of the average yield, and from 77 per cent. to 82 per cent. of the rainfall. The average annual waste is from 84,000,000 to 62,000,000 cubic feet, and the smallest storage in any year is equal to from fifteen up to one hundred and forty days' supply, according to the quantity used. To afford a supply of 180,000,000 cubic feet, or 88 per cent. of the average yield, and 95 per cent. of the average rainfall, the case marked No. 9 shows that the reservoir must store 340,000,000 cubic feet, a quantity equal to 150 per cent. of the average rainfall and to 166 per cent. of the average yield of the drainage area. The number of days' supply which it is necessary to store varies from six hundred and fifty-six up to seven hundred

and thirty among the cases cited, but for perfect safety the reservoir should contain two years' supply.

The quality of the water discharged by the drainage area is shown by the following analysis, made by the Chemical Examiner to the Government of Bengal in 1865 :—

In 70,000 *Grains* :—

	Grs.
Solid residue	6·9
Organic Matter	1·8
Silica	0·6
Carbonate of Lime	1·41
Carbonate of Magnesia	1·59
Chloride of Sodium	0·42
Sulphate of Soda	a trace
Carbonate of Soda	1·08

That sample was taken from the old tank, but as the area and the depth and capacity of the reservoir are now largely increased, the probability is that the water is purer.

Evaporation.

In India a most important matter for consideration is the amount of evaporation. Not only is a large portion of the actual rainfall thereby lost before it flows off the ground during the monsoon months, but a large quantity is evaporated from the surface of the reservoir during the long, hot, and dry season, extending from October to June. During this time no portion of the average rainfall of 3·21 inches flows off the ground, although the actual surface of the reservoir is raised by the rain which falls upon it.

To determine the quantity evaporated from the surface is a matter of difficulty. But the Author during the dry season of 1872–73 attempted, by carefully observing the level of the water in the reservoir, and by comparing the result with the existing meteorological circumstances, to estimate the amount. The result is given in Table V. It will be observed from column 2, that the total loss of water from all causes during the dry season of two hundred and forty-two days, extending from the 10th of October, 1872, to the 9th of June, 1873, was a depth of 7 feet, or at the average rate of 0·0289 foot per day. This at once disposes of the large amounts of 8 feet, and even 10 feet, sometimes asserted to be the evaporation in India during the dry season. From columns 5 and 8 it will be seen that this diminution varied from 1 foot in

twenty-two days, or 0·0454 foot per day, to 1 foot in forty-two days, or 0·0238 foot per day, and that, commencing with a diminution of 0·0286 foot in October and November, it fell to 0·0238 foot in December and February, rising to 0·0454 foot in April and May, and finally declining to 0·0303 foot during May and June. The Author believes that this wave-like rise and fall in the total loss to the reservoir is due to the increase and decrease of the evaporation, and this is confirmed by the meteorological observations in column 15. These show that when the comparative humidity of the air was least the diminution was greatest, as during the period from the 15th of April to the 7th of May, and that when the air was most humid, during December and February, the diminution was least. It will be noticed that the period of maximum loss occurred when the comparative humidity was the least recorded, viz., 0·37. Columns 12, 13, and 14 prove that the greatest loss of water does not occur when the temperature of the air is greatest; for both the maximum and the mean temperatures were less during April and May, and the maximum evaporation in April, when the total loss varied from 0·0498 foot to 0·0454 foot per day, was less than during May and June, when the temperature was highest, and the loss was only 0·0303 foot per day. The temperature of the water at a depth of 5 feet below the surface generally agreed, within 1°, with the mean temperature of the air; thus in June it varied from 90° to 92°; and on the 24th of May, 1873, the temperature of the water flowing in the river Kanhan was 96° at 9 A.M.

It is believed that a near approximation to the quantity of water evaporated, out of the total daily loss shown in column 7, will be arrived at by deducting 200,000 cubic feet per day for the quantity used in the city, and for soakage through the ground on which the reservoir stands. This is the basis of calculation in the quantities and depths stated in columns 9 and 10, in which the amounts of evaporation vary from 163,357 cubic feet, and 0·0107 foot up to a maximum of 506,350 cubic feet, or 0·0357 foot per day. From the figures given in column 10 it is found that the evaporation amounted to 3·75 feet, but to this must be added 3 inches of rainfall, registered in various small showers from October to June; so that the total depth evaporated may be taken at 4 feet, which, distributed over the two hundred and forty-two days, gives an average of 0·0165 foot, or 0·198, say $\frac{1}{5}$ inch per day.

The importance of the question of evaporation to the reservoir at Nágpúr may be inferred from columns 3 and 6. The total loss of water during the season amounted to 104,180,000 cubic feet,

out of which, by the above calculation, 55,781,000 cubic feet were evaporated, leaving only 48,399,000 cubic feet as used or absorbed; in other words, of the total quantity lost to the reservoir during the dry season the proportion evaporated was 54 per cent.

Fluctuation of Rainfall in India and in other Places.

In designing reservoirs, not only should the amount of annual rainfall be considered, but the fluctuations to which it is liable. In England the question has long received careful study, and certain rough approximate rules have been arrived at, so that an idea can be formed of the variations to which the mean annual quantity is subject. In designing these works, however, the Author had some difficulty in deciding on this matter, as it was his first work in India, and as it was said that rules good for England were inapplicable to the tropics. Accordingly, the Author was led to analyse the records of rainfall at Calcutta, Madras, Bombay and Nágpúr, at the same time comparing them with the records kept for longer or shorter periods in other places in different parts of the world. The results, with subsequent additions, are epitomised in Table VI. To arrive at a common standard of comparison, the mean annual amount of rain has been adopted, and in doing so care has been taken to admit no records which do not extend over at least nineteen years. In all cases this mean annual amount, varying as it does from 16·44 inches at Prague to 76·80 inches at Bombay, is taken as unity; and the proportions above or below are expressed as unity plus a decimal part, where it rises above the mean annual amount, or a decimal part of it where it falls below.

The points which have received attention are the percentages in the number of years whose rainfall is above or below the average; the average fall of all the years when the rainfall rises above the average, and when it is below it; the average rainfall of the three driest consecutive years; the maximum and minimum yearly rainfall, with the range or extreme difference; the number of periods of three consecutive years of rainfall below the average which may be expected from the records to occur in every hundred years; the greatest number of consecutive years in which the fall of rain is below the average; and, lastly, the average rainfall of the greatest number of consecutive years below the average.

By working out one case, the *modus operandi* will be understood, and an opinion can then be formed of the value to be attached to

the Author's deductions. For this purpose Calcutta is selected. The average annual rainfall for thirty-seven years, from 1836 to 1872, is 66·75 inches. During this period there were sixteen years when the rainfall was above, and twenty-one years when it was below the average, giving percentages of 43 and 57 respectively. The average fall of rain in the sixteen wet years was 77·47 inches, which, expressed in terms of 66·75, the mean annual fall considered as unity, is 1·16. In the same way the average fall of rain in the twenty-one dry years is 58·6 inches, or 0·88 of the mean annual fall. The average fall of the three years 1836, 1837, and 1838, all of which were dry, was 47·33 inches, or 0·71 of 66·75 inches considered as unity. The wettest year on record was 1871, when the fall was 93·31 inches; and the driest 1837, when it was only 43·61 inches. These quantities, reduced to terms of the general mean average, give 1·4 and 0·65 respectively, and the difference between them is 0·75.

During these thirty-seven years, there were six periods of three consecutive years each when the average rainfall was below the mean, viz., 1836–38, 1839–41, 1843–45, 1851–53, 1856–58, and 1865–67; therefore, in the same proportion, 16·2 such periods may be anticipated in every hundred years. The rainfall of each of the six years, 1836–41, was below the general mean, and as the average of those six years was 54·44 inches, it is expressed as 0·83 of the general mean 66·75 inches.

Table VI., with its record of fourteen places situated in every quarter of the globe, the observations at which extend over periods varying from nineteen to sixty years, shows a similarity in the results obtained, notwithstanding the differences of climate, geographical position, and the varying amounts of the mean annual rainfall. A perfect agreement cannot be looked for, but the nature of the fluctuations is the same, and it may be expected that, as rainfall observations are extended, the difference will become better understood. In the majority of instances, the number of dry years exceeds the wet ones in the proportion of 54·2 to 45·8, the greatest divergence being 7·8 per cent., in the case of New Bedford, U.S. With regard to the average fall of all the years when the rain is in excess, the accordance is very striking, the average being 1·19, and the greatest difference, in the case of Madras, only amounting to 9 per cent. Again, the proportion of the fall of the years when the amount is scanty is 0·83, or within 6 per cent. of Madras and Hobart Town, the two extreme results. For the period of the three consecutive driest years, the average of all the observations is 0·76, and the greatest divergence from

this is in the case of Madras, where it amounts to 11 per cent. Taking into consideration the maximum fall, the average of all the cases being 1·52, the greatest difference is 30 per cent. at Madras. In like manner the average of the minimum fall is 0·59; the greatest departure from which is again at Madras, where it is 21 per cent. Thus, as the average range is 0·93, it differs from Madras by 51 per cent; but in the case of maximum and minimum falls, it must be remembered that the records are for single years of the greatest known extremes, and a perfect accordance is not to be anticipated. The general average of the periods of three consecutive years' rain below the mean, which may occur in every hundred years, is 20·3, the greatest difference being at Calcutta, where it is 16·2.

In the various cases recorded, periods of from nine consecutive years downwards have occurred, in all of which the fall of rain has been below the average. This is a matter which does not allow of an average being struck; but it is a guide to what may occur. The mean fall of the greatest number of consecutive dry years agrees almost exactly with that of all the years below the average, and the general average of all the cases in the last column is 0·82, within 1 per cent. of the general mean of all the years of minimum fall. The Author does not wish, from the foregoing remarks, to be regarded as advocating a strict rule to be applied in all cases, or as urging new views on the subject, but merely as directing attention to certain general and broadly-marked features, common to all parts of the world; and particularly as pointing out their applicability to India, notwithstanding the other peculiarities of the rainfall in that country.[1]

[1] No inquiry likely to throw light on the investigation of this important subject should, however, be neglected. The sun, as the great source of light and heat, is the principal agent in producing rain. Were this not capable of proof on other grounds, the results in Table VI. would lead the mind to look for a single force continually acting on all parts of the globe, to produce the general uniformity there observed.

During the past few years it has been suggested that the periods of fluctuation of the spots on the sun's disc bear a relation to the fluctuations of rainfall, similar to those which have been demonstrated in the case of terrestrial magnetism. To test the truth of this statement, a comparison was instituted between the fluctuations in the rainfall at the fourteen places referred to in Table VI., and the solar spot periods from Schawbe's observations, as given by Proctor, from 1826 to 1869. The latter included four periods of maximum spot frequency, viz., 1828–30, 1836–38, 1847–49, and 1859–61; and four periods during which the sun's disc was almost free from spots, viz., 1832–34, 1842–44, 1854–56, and 1866 and 1867. No satisfactory result or accurate deductions can be drawn from this test; but during

Concluding Remarks.

In conclusion the Author would suggest to the younger members of the profession who wish to enter the Public Service in

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the period when the spots are about a maximum, great fluctuations in rainfall occur, principally, but not without many exceptions, in the direction of an excess above the mean annual fall; and during the time when the sun is least obscured, the fluctuations approach near to the average or fall below it. Moreover, a longer period elapses during which the spots are fewer than when the obscuration is great. The proportion is as 38 to 62; which corresponds, as will be seen in Table VI., to within 8 per cent. of the average of the percentages in the numbers of the years which rise above or fall below the average, and is in agreement with the cases of Barbadoes and New Bedford. Taking now these proportions of the spot curve, 38 and 62, and comparing them with the average amount of the fall of years above and below the mean, which is shown in Table VI. to be 1·19 and 0·83, and which are to each other as 59 to 41, they are almost complements of each other; thus 38, the proportion of the spot curve corresponding to the maximum, added to 59, the proportion of the rainfall in years above the average, is equal to 97; while 62, the proportion of the spot curve corresponding to a minimum, added to 41, the proportion of the rainfall in years below the average, is equal to 103. From Table VI. it appears that the average number of periods of three consecutive dry years per hundred years is 20·3; that is, at distances apart of 4·92 years, agreeing, within 8 per cent., with the half of the ten-year period, which, according to Schawbe's observations from 1826–69, separates the fluctuations of the solar spots. Table VII. is a statement of the rainfall in inches, at the fourteen places in Table VI., during the three-year maximum and minimum sun-spot periods from 1828–67. If the sun-spot periods do affect directly the fluctuation of rainfall, this Table should show an increase and decrease in the total amounts of rainfall during the three-year maximum and minimum sun-spot periods; but no such wave-like rise and fall in the amount of rain is found, for any long period, through any one series, excepting in the case of Prague; all the other cases, with slight exception, being more or less confusing. Turning now from individual cases, to the consideration of the sum of the results of Calcutta, Bombay, Madras, Greenwich, and Prague, extending over the six periods from 1836–67, as given in Table VIII., the average total fall is 689·23 inches; a comparison of this amount with the actual total falls does not show an approach to a satisfactory result, except in the four latter periods, extending from 1847–67. But it is only in the case of the seven places in Table IX. which extend over the four periods from 1847–67, or that of the nine places in Table X., extending only over the three periods from 1854–67, that there is any approach to a wave-like rise and fall in the amount of rain, corresponding with the maximum and minimum sun-spot periods. In the present state of knowledge of the subject, the connection between sun-spot periods and the amount of rainfall is not capable of demonstration; and even assuming the results of the short periods dealt with in Tables IX. and X., and the last four periods in Table VIII., to represent the amount of the fluctuation due to the solar-spot periods, yet it is so small (the extreme average fluctuation amounting to only about 13 per cent.) that, when compared with the other larger and well-established fluctuations shown in Table VI., it may for professional purposes

India, that in a project, such as this, they may be called on not only to prepare the plans, sections, working drawings, and specifications, but also to study great natural laws in the general design; and during the construction of the works they will not have the assistance of the trained staff of a large contractor, but may have to arrange, prepare, and work all the necessary plant and organise the workpeople. A knowledge of accounts is a most useful acquisition; in India this is almost indispensable, as nearly all Government engineers have to keep their own accounts and receive and disburse the money expended on the works. But the most important matter for special attention in carrying on their duties will be, the exercise of careful personal supervision of every detail of construction, and of all the materials with which they have to deal: for the subordinate inspection at their disposal is not of the highest class, nor is it implicitly to be relied upon.

The communication is accompanied by a series of drawings and diagrams, from which Plates 1 to 3 have been compiled.

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be neglected. Possibly the mode of investigation adopted by the Author may not be the correct one: it may be that the effect produced by the sun's action is not contemporaneous on all parts of the globe; yet it is difficult after an inspection of Table VI., and considering the vast forces at work, to think that such is the case. The Author does not feel justified, from the result of the above investigation, and with the materials at present at his disposal, in drawing other or more exact deductions; but he hopes the subject will receive the attention it merits from those better able to deal with it than himself. He is, however, of opinion that attention should in all cases be directed to general facts, and the mind be withdrawn from too close a study of variations within limited areas, as he conceives it will be easier to work from well-ascertained principles, common to the whole world, down to the details of particular countries, rather than the reverse.

APPENDIX.

TABLE I.—MONTHLY, MONSOON, and ANNUAL RAINFALL at NÁGPÚR for the NINETEEN YEARS 1854–5 to 1872–3.[1]

Months.	1854–5.	1855–6.	1856–7.	1857–8.	1858–9.	1859–60.	1860–1.	1861–2.	1862–3.	1863–4.	1864–5.	1865–6.	1866–7.	1867–8.	1868–9.	1869–70.	1870–1.	1871–2.	1872–3.	Averages.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches	inches.	inches	inches.	inches.	inches.	inches.	inches.	inches.
June . .	6·43	5·40	7·20	10·52	3·85	6·59	4·76	13·84	10·48	10·44	7·34	10·60	6·20	14·50	4·00	4·12	9·49	12·80	4·01	8·03
July . .	24·81	7·50	24·00	4·46	11·96	6·36	15·23	17·16	1·57	15·66	9·10	13·46	10·10	12·70	8·87	8·62	18·98	17·15	7·44	12·74
August .	4·44	3·60	10·02	8·56	5·88	14·94	8·72	8·63	11·02	4·24	8·52	8·60	14·42	10·70	4·66	9·61	1·78	2·04	9·35	7·88
September	9·57	4·45	2·79	7·17	9·60	1·51	15·76	1·26	6·66	6·51	4·00	3·70	8·89	13·28	1·67	7·30	5·00	12·86	14·80	7·36
October .	3·15	3·09	0·32	2·75	0·58	0·08	0·03	..	3·56	0·61	..	1·80	1·40	2·54	0·08	2·46	2·09	..	4·22	1·51
Totals of the 5 monsoon months	48·40	24·04	44·33	33·46	31·87	29·48	44·50	40·89	43·29	37·46	28·96	38·16	41·01	53·72	19·28	32·11	37·34	44·85	39·82	37·52
November	..	..	..	..	..	..	..	..	1·07	..	0·97	0·50	..	..	..	..	0·59	..	..	0·16
December	..	..	..	..	..	0·71	..	..	0·31	..	..	..	0·20	0·05	..	0·39	..	0·20	0·05	0·10
January .	0·98	..	0·14	..	..	..	3·11	0·12	0·12	2·04	..	..	..	4·84	..	2·14	0·17	..	..	0·72
February	0·45	..	0·06	2·07	..	0·41	..	..	..	..	..	1·90	..	..	..	..	0·20	..	1·02	0·32
March .	0·52	..	0·04	0·41	..	0·05	0·54	..	1·59	..	3·60	..	0·34	0·72	0·68	0·98	..	0·06	0·70	0·54
April . .	0·11	..	0·62	..	3·93	..	..	0·05	..	0·74	1·30	..	2·60	..	0·20	0·57	..	1·01	0·35	0·60
May . .	..	2·03	1·91	0·84	0·28	0·15	1·35	0·98	0·52	1·95	1·00	..	1·04	0·65	..	0·01	1·33	..	0·58	0·77
Totals of the 7 dry months	2·06	2·03	2·77	3·32	4·21	1·32	5·00	1·15	3·61	4·73	6·87	2·40	4·18	6·26	0·88	4·09	2·29	1·27	2·70	3·21
Annual totals	50·46	26·07	47·10	36·78	36·08	30·80	49·50	42·04	46·90	42·19	35·83	40·56	45·19	59·98	20·16	36·20	39·63	46·12	42·52	40·73

[1] From 1854 to 1865 the observations were made by Lieut. Duncan at the Arsenal at Nágpúr, and from 1866–73 from figures furnished by the Sanitary Commissioner of Nágpúr.

TABLE II.—EXTRAORDINARY SHOWERS at NÁGPÚR DURING the MONSOON of 1872.
Drainage Area, 4,224 Acres.

Dates. 1872.	Rainfall.			Rise of Water in the Reservoir, &c.					
	Amount.	Duration.	Rate of Fall per Hour.	Rise of Water in Reservoir.	Duration.	Total Quantity.	Rate of Flow per Minute.	Rate of Flow per Minute per Square Mile of Drainage Area.	Proportions of Rain flowing from the whole Drainage Area.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	inches.	hours. mins.	inches.	feet.	hours. mins.	cubic feet.	cubic feet.	cubic feet.	
18th June	2·24	1 20	1·684	unimportant.					
3rd July	3·92	24 ..	0·163	1·50	24 ..	9,242,400	6,420	973	0·160
10th July	0·71	.. 20	2·131	0·32	3 ..	2,197,216	12,207	1,849	0·204
12th July	1·26	.. 30	2·520	1·00	3 ..	7,571,800	42,066	6,374	0·392
9th August . . .	0·97	1 30	0·646	0·10	2 ..	965,010	8,041	1,218	0·065
10th August . . .	3·50	1 45	2·000	3·15	3 ..	32,565,960	180,922	27,412	0·607
24th August . . .	1·00	.. 40	1·515	0·60	3 ..	7,803,300	43,352	6,568	0·510
7th September. . .	0·60	1 ..	0·600	0·60	5 30	8,586,000	26,018	3,942	0·940
16th September . .	0·50	.. 30	1·000	0·40	6 ..	5,877,600	16,326	2,474	0·760
	2·20	1 20	1·650	2·20	2 50	33,160,380	195,061	29,555	0·983
6th October . . .	0·50	.. 20	1·500	1·34	3 ..	21,509,520	175,053	26,371	0·346
	3·55	.. 45	4·733						

TABLE III.—PROBABLE DISCHARGE of WATER from the DRAINAGE AREA of 4,224 acres, as deduced from the diagrams (Plate 3), and the RAINFALL RECORD for each YEAR from 1854–5 to 1872–3.

Date.	Monsoon Rainfall.	Proportion Flowing from Ground.	Depth Flowing from Ground.	Yield of the Drainage Area.
	inches.		inches.	cubic feet.
1854	48·40	0·400	19·36	296,240,000
1855	24·04	0·215	5·17	79,120,000
1856	44·33	0·400	17·73	272,320,000
1857	33·46	0·345	11·54	176,640,000
1858	31·87	0·315	10·04	154,560,000
1859	29·48	0·285	8·40	128,800,000
1860	44·50	0·400	17·80	272,320,000
1861	40·89	0·400	16·36	250,240,000
1862	43·26	0·400	17·30	264,960,000
1863	37·46	0·380	14·24	218,960,000
1864	28·96	0·280	8·11	125,120,000
1865	38·16	0·388	14·81	226,320,000
1866	41·01	0·400	16·40	252,080,000
1867	53·72	0·400	21·49	329,360,000
1868	19·28	0·155	3·00	46,000,000
1869	32·11	0·320	10·27	158,240,000
1870	37·34	0·380	14·19	217,120,000
1871	44·85	0·400	17·94	274,160,000
1872	43·65	0·400	17·46	266,800,000
1873	24·25	0·217	5·26	80,960,000
Average . . .	37·00	..	13·343	204,516,000

NOTE.—The rainfall of the years 1872 and 1873 differs from that given in Table I., since in 1871 the rainfall has been gauged at Ambájharí, 3 miles from Nágpúr.

TABLE IV.—PROPORTIONS of RESERVOIRS.—Drainage Area 4,224 Acres.

Rainfall.

	Inches.	
Average	37	= 1·00
Maximum	53·72	= 1·45
Minimum	19·28	= 0·52
Average of three consecutive driest years	29·57	= 0·80

Yield of Drainage Area.

	Million cubic feet.	
Average	204·52	= 1·00
Maximum	329·36	= 1·59
Minimum	46·00	= 0·23
Average of three consecutive driest years	140·44	= 0·69

	Details of the different Cases.				Storage in Reservoir.			Annual Supply.			Average Annual Waste.		Minimum Storage.	
Number of Case.	Storage of Reservoir.	Annual Supply, including Evaporation.	Average Annual Waste.	Minimum Storage.	In Terms of Average Yield.	In Terms of Average Rainfall.	In No. of Days' Supply.	In Terms of Average Yield.	In Terms of Average Rainfall.	In Terms of Total Storage.	In Terms of the Average Yield.	No. of Years during which the Reservoir would have Overflowed.	In Terms of Annual Supply.	In Days' Supply.
	million cubic feet.	million cubic feet.	million cubic feet.	million cubic feet.										
1	240	120	84·47	46	1·17	1·06	730	0·586	0·771	0·50	0·414	17	0·38	140
2	240	130	71·57	26	1·17	1·06	675	0·635	0·818	0·54	0·365	14	0·20	73
3	240	140	62·47	6	1·17	1·06	656	0·684	0·821	0·58	0·316	14	0·04	15
4	270	150	51·97	16	1·32	1·19	657	0·733	0·853	0·55	0·267	13	0·11	38
5	288	150	52·31	34	1·41	1·27	700	0·733	0·853	0·52	0·267	13	0·23	85
6	288	158	43·87	18	1·41	1·27	665	0·772	0·865	0·55	0·228	12	0·11	41
7	300	160	41·47	26	1·47	1·32	684	0·782	0·871	0·53	0·218	11	0·16	59
8	330	165	35·47	45·36	1·61	1·45	730	0·806	0·886	0·50	0·113	9	0·27	100
9	340	180	21·47	4·24	1·66	1·50	688	0·880	0·953	0·53	0·120	6	0·02	8

Facts or Data.					Total Loss to Reservoir.			Approximate Evaporation.		Meteorological Observations.					
Date.	Height of Water on Gauge.	Quantity of Water in the Reservoir.	Area of the Reservoir.	No. of Days to fall 1 foot.	Total quantity lost per foot of fall over mean area.	Total average quantity lost per day.	Total average fall per day.	Daily quantity evaporated if 200,000 cubic feet are drawn off.	Depth evaporated per day if 200,000 cubic feet are drawn off.	Average Barometer.	Temperature. Average. Max.	Temperature. Average. Min.	Temperature. Mean.	Humidity.	Date.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
	feet.	cubic feet.	square feet.		cubic feet.	cubic feet.	foot.	cubic feet.	foot.	inches.	°	°	°	satur. = 1·00.	
1872 10th Oct.	22	249,898,500	16,206,000												
				35	16,017,000	457,629	0·0286	257,629	0·0161	28,871	87·5	61·3	74·5	0·77	10th Oct. to 14th Nov.
14th Nov.	21	233,881,500	15,828,000												
				40	15,639,000	390,975	0·0250	190,975	0·0122	28,919	84·2	57·6	70·9	0·80	14th Nov. to 24th Dec.
24th Dec.	20	218,242,500	15,450,000												
				42	15,261,000	363,357	0·0238	163,357	0·0107	28,933	84·9	53·7	69·3	0·82	24th Dec. to 4th Feb.
1873 4th Feb.	19	202,981,500	15,072,000												
				40	14,883,000	372,075	0·0250	172,075	0·0115	28,859	92·3	62·0	77·2	0·63	4th Feb. to 16th Mar.
16th Mar.	18	188,098,500	14,694,000												
				30	14,505,000	483,500	0·0333	283,500	0·0195	28,758	104·2	73·2	88·7	0·51	16th Mar. to 15th Apr.
15th Apr.	17	173,593,500	14,316,000												
				22	14,127,000	642,136	0·0454	442,136	0·0312	28,716	107·2	76·3	91·7	0·38	15th Apr. to 7th May.
7th May	16	159,466,500	13,938,000												
				33	13,749,000	416,636	0·0303	216,636	0·0157	28,620	105·7	79·5	92·6	0·63	7th May to 9th June.
9th June	15	145,717,500	13,560,000												
18th April	16·90	172,180,800	14,279,200												
				20	8,476,200	706,350	0·0498	506,350	0·0357	28,720	107·9	74·7	91·3	0·37	Maximum Observation.
30th April	16·30	163,704,600	14,051,400												

TABLE VI.—FLUCTUATIONS of the RAINFALL as OBSERVED at FOURTEEN STATIONS, the PERIODS of OBSERVATION EXTENDING from NINETEEN to SIXTY YEARS, the VARIATIONS BEING EXPRESSED in TERMS of the MEAN ANNUAL RAINFALL at EACH STATION.

Place of Observation.	Period of Observation.			Mean Annual Rainfall.	Percentage of Years above the Average.	Percentage of Years below the Average.	Average Fall of all the dry Years.	Average Fall of all the rainy Years.	Average Fall of the three driest consecutive Years.	Maximum Fall.	Minimum Fall.	Extreme Range.	Proportionate Number of Periods of 3 consecutive dry Years per 100 Years.	Greatest Number of consecutive dry Years.	Average fall of the greatest Number of consecutive dry Years.
	From	To	Years.	Inches.											
Calcutta[1] .	1836	1872	37	66·75	43	57	1·16	0·88	0·71	1·40	0·65	0·75	16·2	6	0·83
Bombay[2]. .	1817	1872	56	76·80	45	55	1·20	0·84	0·73	1·59	0·44	1·15	17·8	5	0·84
Madras[3] . .	1813	1872	60	48·60	45	55	1·28	0·77	0·65	1·82	0·38	1·44	21·7	9	0·76
Nágpúr[4] . .	1854	1872	19	37·52	53	47	1·17	0·80	0·79	1·43	0·51	0·92	21·0	3	0·79
Mauritius[5] .	1853	1872	20	42·95	50	50	1·20	0·80	0·67	1·60	0·48	1·12	20·0	3	0·67
Barbadoes[6] .	1843	1863	21	56·07	38	62	1·21	0·87	0·84	1·35	0·76	0·59	19·0	4	0·87
Adelaide[7] .	1839	1860	22	21·80	41	59	1·20	0·85	0·80	1·40	0·68	0·72	22·7	5	0·84
Hobart Town[8]	1841	1870	30	22·71	53	47	1·19	0·77	0·78	1·79	0·59	1·20	16·6	3	0·78
Cape Town[9].	1842	1872	31	24·21	45	55	1·17	0·86	0·78	1·52	0·77	0·75	19·3	5	0·82
New York[10] .	1836	1854	19	42·77	42	58	1·22	0·84	0·81	1·53	0·64	0·89	21·0	6	0·84
Rome[11] . .	1821	1860	40	30·18	50	50	1·20	0·80	0·73	1·55	0·43	1·12	25·0	6	0·81
Greenwich[12].	1820	1872	53	25·04	45	55	1·17	0·85	0·81	1·45	0·67	0·78	22·6	5	0·81
New Bedford U.S.[13] . .	1814	1855	42	41·40	38	62	1·18	0·89	0·86	1·40	0·74	0·66	23·8	9	0·90
Prague[14]. .	1832	1870	39	16·44	54	46	1·14	0·83	0·74	1·44	0·58	0·86	17·9	4	0·95
General averages . .	..	..	..	..	45·8	54·2	1·19	0·83	0·76	1·52	0·59	0·93	20·3	..	0·82

1 Observatory, published in Thacker's Bengal Directory for 1873. Checked by "Calcutta Gazette."
2 At Byculla, 1817–32, G. J. Symons; 1832–73, "Bombay Calendar," 1873; checked by "Bombay Gazette."
3 Madras Observatory, 1813–66, vol. v. Balfour's "Cyclopædia of India"; 1866–72, "Madras Gov. Gazette."
4 Monsoon rainfall, 1854–65, at Nágpúr Arsenal, Lieut. Duncan; 1865–72, Nágpúr Sanitary Commissioner.
5 Port Royal; monthly notices Met. Soc. of Mauritius.
6 Halton St. Philip, "Met. Mag.," 1864.
7 "Quarterly Journal Met. Soc."
8 Results of Met. Obs. published at Hobart Town, 1866 and 1872.
9 Met. Obs. Royal Obs., Cape of Good Hope, by Sir Thos. Maclean.
10 Fort Columbus, U.S. Army Medical Reports, 1856.
11 Beardmore, "Manual of Hydrology."
12 Minutes of Proceedings Inst. C.E., vol. xxxi., 1870–69; Met. Soc., 1869–72.
13 Mr. Symons, checked by "Smithsonian Rain Tables," 1872.
14 Monthly notices Met. Soc. of Mauritius.

TABLE VII.—RAINFALL during the

Place.	Average.	Maximum, 1828–30.		Minimum, 1832–34.		Maximum, 1836–38.	
		Inches.	Totals.	Inches.	Totals.	Inches.	Totals.
	Inches.						
Calcutta	66·75	..	..	..	..	45·39 43·61 52·99	141·99
Bombay	76·80	121·98 65·65 71·86	259·49	74·09 71·39 70·47	215·95	87·99 64·58 50·78	203·35
Madras	48·60	37·89 36·87 32·43	107·19	18·45 37·12 39·00	94·57	44·68 49·26 52·33	146·27
Nágpúr	37·53	..	..	..	..	..	..
Mauritius	42·95	..	..	..	..	..	..
Barbadoes	56·07	..	..	..	..	..	..
Adelaide	21·80	..	..	..	..	..	..
Hobart Town . . .	22·71	..	..	..	..	..	..
Cape Town	24·21	..	..	..	..	..	..
New York	42·77	..	..	..	..	27·57 65·51 41·90	134·98
Rome	30·18	18·00 34·30 28·60	80·90	22·80 26·00 13·00	61·80	30·80 25·10 31·40	87·30
Greenwich	25·04	31·50 25·20 27·20	83·90	19·30 23·00 19·60	61·90	27·10 21·00 23·80	71·90
New Bedford, U.S. . .	41·40	36·00 58·10 57·50	151·60	43·80 37·90 40·10	121·80	38·10 34·70 34·00	106·80
Prague	16·44	..	..	10·88 19·35 10·13	40·36	16·63 18·63 16·00	51·26

MAXIMUM and MINIMUM SUN-SPOT PERIODS.

Minimum, 1842–44.		Maximum, 1847–49.		Minimum, 1854–56.		Maximum, 1859–61.		Minimum, 1865–67.	
Inches.	Totals.	Inches.	Totals.	Inches.	Totals.	Inches.	Totals.	Inches.	Totals.
76·11 63·34 73·86	213·31	72·36 58·69 70·51	201·56	66·47 70·46 64·23	201·16	68·66 52·61 89·19	210·46	61·58 65·74 72·73	200·05
95·16 59·27 65·40	219·83	67·31 73·42 118·88	259·61	89·79 35·10 71·08	195·97	81·84 74·65 106·08	262·57	73·46 92·39 73·57	239·42
36·48 50·28 65·36	152·12	80·99 54·76 39·81	175·56	43·20 32·32 46·99	122·51	55·14 27·64 37·18	119·96	41·86 51·39 24·37	117·62
..	..	..	..	48·40 24·04 44·33	116·77	29·48 44·50 40·89	114·87	38·16 41·01 53·72	132·89
..	..	..	..	39·45 42·66 46·23	128·34	56·87 45·17 68·73	170·77	44·73 20·57 35·97	101·27
..	..	42·48 62·85 53·04	158·37	45·11 73·53 46·37	165·01	55·08 60·44 71·07	186·59	..	..
20·32 17·19 16·88	54·39	27·61 19·74 25·44	72·79	15·35 23·15 24·92	63·42	..	..	..	..
23·60 13·43 26·25	63·28	14·46 23·62 33·51	71·59	30·56 18·25 22·73	71·54	23·31 21·05 28·19	72·55	23·07 23·55 22·27	68·89
26·27 24·82 18·78	69·87	22·38 23·25 24·62	70·25	20·05 24·57 19·48	64·10	36·72 29·12 25·44	91·28	18·67 19·21 22·96	60·84
32·98 41·37 36·38	110·73	64·85 36·80 31·74	133·39	..	..	..	..	..	..
32·90 21·30 30·60	84·80	31·60 25·40 20·60	77·60	18·80 32·30 28·30	79·40	..	..	..	..
22·60 24·60 24·90	72·10	17·80 30·20 23·70	71·70	18·70 21·10 22·20	62·00	25·90 32·00 20·30	78·20	28·60 30·10 28·50	87·20
34·60 45·00 36·20	115·80	40·80 36·20 32·40	109·40	..	..	..	..	..	..
9·50 17·53 23·68	50·71	23·36 16·98 15·80	56·14	16·45 17·74 14·97	49·16	19·18 20·65 16·55	56·38	12·15 17·58 15·57	45·30

TABLE VIII.—RAINFALL at FIVE PLACES during the SIX MAXIMUM and MINIMUM SUN-SPOT PERIODS, from 1835 to 1867.

Place	Average.	Maximum, 1836-38.	Minimum, 1842-44.	Maximum, 1847-49.	Minimum, 1854-56.	Maximum, 1859-61.	Minimum, 1865-67.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Calcutta	66·75	141·99	213·31	201·56	201·16	210·46	200·05
Bombay	76·80	203·35	219·83	259·61	195·97	262·57	239·42
Madras	48·60	146·27	152·12	175·56	122·51	119·96	117·62
Greenwich	25·04	71·90	72·10	71·70	62·00	78·20	87·20
Prague	16·44	51·26	50·71	56·14	49·16	56·38	45·30
Total and Average Total	689·23	614·77	708·07	764·57	630·80	727·57	689·59
Difference above or below the Average Total		−74·46	+18·84	+75·34	−58·43	+38·34	+0·36

TABLE IX.—RAINFALL at SEVEN PLACES during the FOUR MAXIMUM and MINIMUM SUN-SPOT PERIODS, from 1847 to 1867.

Place.	Average.	Maximum, 1847–49.	Minimum, 1854–56.	Maximum, 1859–61.	Minimum, 1865–67.
	inches.	inches.	inches.	inches.	inches.
Calcutta	66·75	201·56	201·16	210·46	200·05
Bombay	76·80	259·61	195·97	262·57	239·42
Madras	48·60	175·56	122·51	119·96	117·62
Hobart Town . .	22·71	71·59	71·54	72·55	68·89
Cape Town . . .	24·21	70·25	64·10	91·28	60·84
Greenwich . . .	25·04	71·70	62·00	78·20	87·20
Prague	16·44	56·14	49·16	56·38	45·30
Total and Average Total . . .	845·89	906·41	766·44	891·40	819·32
Difference above or below the Average Total		+60·52	−79·45	+45·51	−26·57

TABLE X.—RAINFALL at NINE PLACES during the THREE MAXIMUM and MINIMUM SUN-SPOT PERIODS, from 1854 to 1867.

Place.	Average.	Minimum, 1854–56.	Maximum, 1859–61.	Minimum, 1865–67.
	inches.	inches.	inches.	inches.
Calcutta	66·75	201·16	210·46	200·05
Bombay	76·80	195·97	262·57	239·42
Madras	48·60	122·51	119·96	117·62
Nágpúr	37·53	116·77	114·87	132·89
Mauritius	42·95	128·34	170·77	101·27
Hobart Town	22·71	71·54	72·55	68·89
Cape Town	24·21	64·10	91·28	60·84
Greenwich	25·04	62·00	78·20	87·20
Prague	16·44	49·16	56·38	45·30
Total and Average Total .	1080·69	1011·55	1177·04	1053·48
Difference above or below the Average Total		−69·14	+96·35	−27·21

[MR. BATEMAN

Mr. Bateman said he had listened with great interest and pleasure to the Paper, as it showed how much the Author, who was an old pupil of his own, had benefited by the opportunities of studying the question of providing for the various contingencies with which the water engineer had to contend in constructing waterworks of different kinds. It also showed, to those who had not been accustomed to investigate such problems, the vast number of circumstances that had to be taken into account before an accurate estimate of the yield of districts, or of the works to be executed, could be arrived at. The Nágpúr Waterworks seemed to have been carefully designed with reference to the particular conditions under which they had to be constructed, every difficulty having been foreseen and carefully provided for. The escape of water, the retention of the water by embankment, the means by which the water should be discharged through pipes, the protection of the pipes that they might not break by unequal pressure, and other details, had been carried out with perfect success. But by far the most important part of the Paper consisted of the record of the Author's observations upon the great variations in the rainfall in various parts of the country, and in different seasons, whether at the commencement of the wet season, or at its termination. Mr. Binnie had supplied a table, with diagrams, showing the rise and fall of the rain, and the deviations from the mean occurring at different periods of the year. He would draw special attention to a point of great importance, not only in its bearing on the supply of water, but likewise in all cases where a free passage of water had to be provided for, namely, the amount of water flowing off the ground under certain circumstances. It had been his lot to investigate the subject to a great extent. In steep hilly districts, where the streams were short, receiving the water falling upon mountain ranges, and where the rainfall was 2, 3, or 4 inches in twenty-four hours, floods were common of about 25 cubic feet, and occasionally up to 40 feet, and even 50 cubic feet per second to every hundred acres. On three occasions referred to by Mr. Binnie during the monsoon of 1872, extending from June to October, it appeared that the quantity of water flowing off the ground amounted to between 70 and 80 cubic feet per second per hundred acres, being nearly twice as much as the heaviest floods in the ordinary mountain districts of this country. He referred especially to the Pennine chain of hills between Lancashire and Yorkshire, where the average rainfall was about 40 inches. He was quite aware that in Cumberland and Westmoreland, where the fall was almost tropical, amounting to

between 100 and 200 inches in a year—in such a valley, for instance, as Borrowdale, leading to Derwentwater,—the quantity of water flowing down would probably equal the 70 or 80 cubic feet per second per hundred acres falling at Nágpúr; but after it reached Derwentwater it was moderated; the large surface prevented its flowing from the lake as rapidly as it flowed into it. The water discharge in great areas of country which might be inundated by the overflow of rivers or the flowing from lakes, although they were fed by mountain ranges, was much smaller in volume than in the hilly districts themselves. For instance, the rain at the head of Loch Katrine was occasionally as much as 118 inches in the year, and more than that upon the mountains ascending towards the summit; but the heaviest flood from Loch Katrine itself gave but 12½ cubic feet per second per hundred acres—not more than half the flood on the range of hills between Lancashire and Yorkshire. From Loch Lubnaig, in the adjacent valley of the Lenny, draining an equal area to that of Loch Katrine and Loch Venacher, but where the average was not so great for impounding water as in the valley of Loch Katrine, the floods were slightly greater. In the valley of the Clyde, where a large quantity of land was inundated before the water could be discharged to the sea, the heaviest floods did not amount to more than 10 cubic feet per second per hundred acres. He drew attention to these facts (which were well ascertained, and not mere speculations) because of their importance in regard to the determination of the dimensions of bridges, whether in the case of roads or railways, with floods passing beneath them. Where the whole of the water of a district had to be stored for waterworks purposes, and the water was collected by flood water-courses or "catch-water" works, it was necessary that the channels by which the water was conveyed should be large enough to convey the heaviest floods that might occur; otherwise the rain water would be lost. On these subjects the Paper contained an amount of valuable information well worthy the consideration of all persons engaged in similar works. The Author's calculations as to the space required in order to store the average quantity of rainfall were very valuable. But in this country no attempt was made to effect this, although there were cases in which the amount of storage was so large (as in the case of some lakes and excessively large reservoirs), that nearly, if not quite, the average quantity of water might be collected if a regular quantity were drawn away. If less than the average were drawn, of course when the reservoirs were full, the difference between what

was drawn and the average must necessarily run to waste. But no engineer who was careful to secure the success of his works, ever calculated upon collecting as much as the average rainfall. He considered what might be reasonably calculated upon in two or three consecutive dry years, and made the capacity of the reservoir sufficient to last over the longest drought that might occur. Of these there were many records in this country, and they varied greatly according to the districts. Droughts lasting two hundred and forty days were not uncommon on the eastern coast of England; while one hundred and eighty days might be taken as the maximum on the western coast. Again, a smaller amount of rain required a smaller amount of storage than a large amount of rain. All these calculations had to be taken into account, and carefully determined, before an engineer could be said to have designed works satisfactorily to himself, or to those interested in the water to be supplied. The loss also, not only by vegetation, but by evaporation, which Mr. Binnie said amounted on an average to $\frac{1}{3}$ inch per day during a long drought in India, was a matter of serious consideration in the case of works designed for so hot a climate. In England he believed the evaporation through a long drought was only about $\frac{1}{10}$ inch per day. The loss also by vegetation and absorption varied considerably according to the nature of the country—whether, for instance, it was so steep that the water would flow from it as from a house-roof, or so flat that it would scarcely escape at all. But, as the Author had shown, this depended more upon the capacity of the air for absorbing moisture than upon the temperature of the air. The air might be so humid as to be just upon the point of precipitating rain, in which case no evaporation took place; or it might be so dry as eagerly to absorb moisture, and then evaporation was great. He had himself observed some years ago, that, during the prevalence of an easterly wind, 5 inches of snow (equal to about $\frac{2}{3}$ inch of rain) were taken up by evaporation in about three weeks, although the thermometer was below freezing point.

Major W. R. Johnson said he had lately been concerned in the restoration and improvement of the tank system in the Mysore country, in which there were no less than thirty thousand reservoirs, and in carrying out this work, it had been necessary to consider the proportion of rainfall running off the ground. No accurate data were forthcoming, but from rough observations made from works in action, it was assumed at starting that not more than one-fourth of the rainfall on an average found its way into the reservoirs. In one district in which the soil was light and

sandy, and the greater proportion under the plough, even this was much in excess, and the proportion had there been reduced to one-sixth. In reference to the collection of surface drainage, the nature of the soil, and the condition of the surface, were the first points for consideration. There being a great scarcity of water in the city of Mysore, he had been sent to inquire into the matter, and had ascertained that the tanks formerly filled much more readily than at present. On examination he found that cultivation had much increased in the catchment basin; what was before hard, barren land having been ploughed up. After heavy rain, not a drop of water found its way into some of the supply or drainage channels, the whole having soaked into the ploughed land. He accordingly recommended that, in order to increase the water supply, the land in the catchment basin should be thrown out of cultivation. Accurate surveys were now, for the first time, being made of the drainages and reservoirs in Mysore; and as they were extensive, he trusted that valuable data would shortly be available.

The action of tanks as flood moderators was much more complete and apparent in a system of tanks than in isolated works. When the tanks were situated one above the other in chains, each acted as a moderator to that below, and absorbed, not only so much of the rainfall as they were capable of retaining, but also the excess, which would be distributed over their greatest area of water spread above their weir level, and escape gradually to the tanks below, from which in turn it would be passed off still more slowly to the next in succession, and so on. The result of this was that the rain that might fall in an hour, and but for these tanks would escape nearly as rapidly in a flood, might take days, and even weeks, to pass off, the quantity in excess of the capacity of the reservoirs being absorbed and distributed above the weir levels of each, and transferred slowly and harmlessly. Owing to this, the terminal tank of a series, although having a greater catchment basin, often required a less length of waste weir than tanks above it.

Dr. Pole was glad some data had been given on the subject of evaporation, which was obscure, both practically and theoretically. Practically, there were but few trustworthy facts on record, and it was interesting to know what occurred in India, where the heat and the dryness were often excessive. The data given in the Author's tables appeared to be deduced by a somewhat complex method, but still they were valuable as expressing results on a large scale. Theoretically, the knowledge of the subject was chiefly due to John Dalton, who had

prepared tables for calculating the evaporation under different circumstances; these tables had been often reprinted, and he was not aware that any subsequent investigations had either, on the one hand, invalidated them, or, on the other hand, had added anything important to them. The tables were, however, somewhat troublesome to use in consequence of their peculiar form, and he had endeavoured to find a formula that would bring them into a more convenient shape. Mr. Bateman had stated that the rate of evaporation depended not only on the temperature, but also on the degree of dryness of the air. Dr. Pole would add a third condition that also materially influenced the evaporation, namely the wind, for it was found that evaporation proceeded much more rapidly under a brisk wind than when the atmosphere was calm. Combining these three elements, he had found that the results of Dalton's tables might be roughly represented by a formula as follows: if T = temperature of the atmosphere in degrees Fahrenheit; t = the *dew point*, or the lower temperature at which moisture began to be deposited (and which, when compared with T, showed the state of dryness of the atmosphere); V = velocity of the wind in miles per hour; E = evaporation in inches per diem from a water surface; and A a certain numerical coefficient, then,

$$E = \frac{T^2 - t^2}{A\ (100 - W)}.$$

The value of A would be about 80 for high or summer temperatures, increased to about 100 for low or winter ones. The formula was, he must state, purely empirical, and only professed to give a rough approximation to Dalton's results, in a somewhat more convenient form.

Dalton's tables did not provide for the case where the temperature of the water differed materially from that of the air; probably, according to the experiments of Mr. Dines and others, in this case T should be made to represent the temperature of the water surface, not that of the atmosphere.

He had endeavoured to check Mr. Binnie's evaporation results by Dalton's rules, and although there was some difficulty in making the comparison, owing to the dew point not being given, he found a tolerable agreement in the earlier portions of the table; but the later ones he thought were too low; for under the great heat and dryness marked in some of the lower lines, the evaporation might be expected to be greater than was there given, unless there were exceptional circumstances, not explained.

Dr. Pole believed that experiments on a large scale on evapora-

tion, both from water and land surfaces, were much to be desired, and that any engineer who had the opportunity, and would take the trouble to carry them out efficiently, would be doing a great service, not only to the engineering profession, but to science in general.

Mr. ROGERS FIELD said he had taken great interest in the subject of evaporation, on which, during the last three or four years, he had been carrying out a series of experiments for the Royal Society. He could confirm Dr. Pole's statement as to the want of reliable information on the subject. The records of meteorologists were for the most part worthless. The evaporator employed was generally nothing but a small metal vessel, which, when exposed to the sun, heated the water so much that an abnormal amount of evaporation was obtained, not in the least agreeing with the amount of evaporation taking place from a natural water surface. From preliminary experiments, a few years ago, he was led to suspect that that was the case; he had therefore sought the means of ascertaining the real evaporation from a large surface of water. He had buried in the ground an iron tank 6 feet square and 2 feet deep, and employed an apparatus which would measure the evaporation from it to the hundredth part of an inch—of course taking the rainfall into account. Using the tank as a datum, he had compared with it the evaporators recommended by different authorities, and the result was that the evaporation from them was two or three times the amount obtained from the tank. The amount obtained from the small metal vessels was 40 to 50 inches per annum; while that obtained from the tank was 18 to 23 inches only. As to the mode of calculating the evaporation, he thought that the formula of Dr. Dalton was the correct one. The most convenient mode was to take the elastic force of vapour at the temperature of the water, from that to subtract the elastic force of vapour at the temperature of the dew point, and multiply the difference by a constant, which would give the result in inches per diem: roughly speaking, this constant multiplier was one-half. Of course the wind and other circumstances would affect the result; but he did not think that there were sufficient data available at present to found a formula with regard to these points. There was no question, however, that evaporation increased as the wind increased, so that with much wind the multiplier would be greater than one-half. In Mr. Binnie's table the first datum was wanting, viz., the temperature of the water; but it might be assumed, from what had been stated, that it was the same as the temperature of the air. On that assumption he had calculated what the multiplier would

be in the different periods. The first three periods, from October to November, from November to December, and from December to February, gave very nearly the same multiplier, viz., 1·00; and the other four periods gave multipliers varying from ·36 to ·50, and averaging ·42—not quite a half. He could not help thinking, with regard to the three first periods, that the data were not complete. Under ordinary circumstances in nature, as far as his experience went, a multiplier as high as 1·00 was not obtained; he therefore imagined that in the three periods referred to the temperature of the water was higher than the temperature of the air, or that some data were missing. The multipliers given by the last four periods, on the other hand, agreed very closely with those obtained from his experiments. Great service would be done to meteorological and hydraulic science if these experiments were carried further, including observations on the temperature of the water at the surface. The temperature mentioned in the Paper was at 5 feet below the surface. This might occasionally differ considerably from the temperature at the surface, which was what had to be taken into account in calculating the evaporation.

The Astronomer Royal, Sir G. B. Airy, said he was not prepared to enter into the engineering question, but he desired to say a few words on the concluding portion of the Paper, with reference to the possible relation between the spots on the sun and the amount of rainfall. The subject had engaged the attention of the Board of Visitors of the Royal Observatory, who some time since applied for a regular photographic register of the spots on the sun. This had been arranged after considerable delay, and he hoped that the observations would cast light upon the subject. The suggestion, that the amount of rainfall might depend upon the visible state of the sun's surface, naturally led to the idea that it might be connected with the amount of heat radiated directly from the sun, which was measurable by other means. For examining in some degree the supposed connection between the state of the sun's surface and the amount of rain, it might be advantageous to compare the observed intensity of heat radiating from the sun with the registered rainfall. To ascertain the intensity of the radiant heat, there was at the Royal Observatory at Greenwich a thermometer, with blackened bulb inclosed in an exhausted glass sphere, exposed to the rays of the sun, whose maximum reading was taken every day. This thermometer was brought into action, experimentally, in 1860; but from 1861 the observations had been taken, under the superintendence of Mr. Glaisher, on a

uniform system; and it appeared best to commence comparisons on that year. The rainfall was measured by an extensive series of rain-gauges.

On considering the applicability of the black-bulb readings to the subject before the Institution, it appeared unadvisable to adopt the mean of the daily readings for any length of time as a measure of the sun's radiant power. In this inquiry, it was not a question of measuring the sun's heat as it reached the earth through clouds, but, as nearly as possible, to measure the heat as it would come from a perfectly pure sky. In the following comparison, therefore, only the highest reading of the black-bulb thermometer in each month was used; there was, however, placed in the same table the mean of the readings for every day in each month. For the rain, the aggregate of rainfall through each month must be taken. This operation being completed for each month, the means of the monthly means of blackened thermometer, and the aggregates of monthly aggregates of rain, were taken for each year. Then the years were arranged in the order determined by the order of thermometer-means. Thus the following table was formed :—

Year.	Yearly mean of highest thermometer-reading in each month.	Yearly mean of all thermometer-readings in each month.	Total rainfall in each Year.
	°	°	inches.
1864	101·8	79·2	16·38
1863	103·4	84·6	19·67
1862	109·4	83·7	26·45
1861	113·6	89·0	20·56
1869	116·5	90·4	24·02
1867	118·2	91·0	28·46
1865	118·3	94·0	28·70
1871	119·4	93·1	22·30
1870	122·1	93·3	18·55
1873	123·2	94·3	23·36
1872	124·3	97·8	30·02
1868	125·6	98·9	25·15
1866	126·4	95·0	30·72

The means of the yearly results in each group gave the following results :—

Means of highest thermometer-readings in each month.	Means of annual rainfalls.
°	in.
102·6	18·03
113·2	23·68
118·6	26·49
124·3	25·56

Thus it appeared—what he should not have supposed if he had not been led by the Paper to look into the matter—that the more scorching the sun, the greater was the quantity of rain that fell. The general correspondence of high readings of the black-bulb thermometer and large rainfalls was remarkable. There were, however, some anomalies in the details which made it imprudent at present to draw from this apparent correspondence any absolute conclusion. This caution was not without reason, for he had observed many instances in which a law seemed at first to be followed out, but had afterwards to be set aside. An instance of this was the supposed law that the daily phenomena of magnetism recurred in periods of ten or eleven years, a supposition which had been entirely negatived by an extended series of observations at Greenwich. The same thing might occur with regard to the figures cautiously cited by Mr. Binnie. One circumstance would not be forgotten, namely, that in different parts of the earth the fluctuations of rainfall had different orders. There appeared, however, to be, from 1861 to the present time, a distinct connection between the scorching of the sun and the amount of rainfall. It was only by following up these observations that the truth in such obscure matters could be ascertained.

Mr. G. Dines was surprised to learn that a place in British India, within the tropics, did not appear to have a much greater amount of rainfall than was experienced in Great Britain at the same elevation. He had made numerous experiments on the subject of evaporation, the result of which would be found in the proceedings of the Meteorological Society for November 1870,[1] where he had attempted to show the principles on which evaporation depended, the uselessness of the gauges ordinarily employed,

[1] *Vide* Proceedings of the Meteorological Society, vol. v., p. 199.

and the reasons of their failure. He had taken up the matter as an amusement; but to engineers connected with hydraulic works it must be of the greatest importance. There was no reason why there should not be returns of daily evaporation from many places in England, as regular as those connected with the rainfall. He had long thought that the amount of evaporation in tropical countries had been overestimated, but had had no opportunity of testing the truth of that opinion until a short time since, when Captain Toynbee sent him a Paper in which the temperature of the sea and also of wet and dry bulb thermometers near the tropics were given. From the figures in that Paper he had calculated the amount of evaporation at 55 inches, so far nearly agreeing with Mr. Binnie's observations. Mr. Field had found it difficult to reconcile the figures in the upper part of one of the tables with those in the lower part. Mr. Dines differed from him as to which figures were correct; but possibly they might both be wrong, and Mr. Binnie might be right. It appeared from the table that the amount of evaporation with a mean temperature of 74° was greater than with a mean temperature of 92°. High temperatures warmed the surface of the water, but he was not sure whether they did not retard rather than promote evaporation; and he had no hesitation in saying that, supposing the temperature of the water to remain constant, the evaporation on a cold windy day would be much greater than it would be under the burning sun of the tropics in calm weather. Evaporation was greater when the air was dry than when it was moist, as might be expected. Whenever the air was dry the dew point was low. In his opinion the amount of evaporation was proportional to the difference between the tension of vapour at the temperature of the water and that of the dew point. That was nothing more nor less than the old law of Dalton. Experiments he had made with water, varying in temperature from 180° downwards, and with evaporation amounting from 11 inches in a day down to nothing, proved, almost to a certainty, the correctness of that law. The equation $x\ (w - d) = \mathrm{E}$ represented it in a simple form, in which w represented the tension of vapour at the temperature of the water, d the tension of vapour at the temperature of the dew point, and E the evaporation. There was, however, one uncertain quantity in the equation which caused the difference of opinion between Mr. Field and himself, and which Dr. Pole had tried to remedy by a formula. That was the value of x. In a room with the doors and windows closed, x maintained its value steadily, but it was changed by the slightest movement

of the air, and in his experiments he had found it vary from ·0118 to ·0742. In Dalton's table the value of x would be represented by the figures ·0336, ·0472 and ·0538. He thought the best experiments were those made by Mr. Greaves at the East London Waterworks, Old Ford, Bow. The only objection he had to them was that the water was not sufficiently near the edge of the vessel. He did not suppose that the temperature at Old Ford differed much from that at Greenwich, and the Greenwich tables gave all the figures that were necessary, if figures could determine the question. He had compared the experiments of Mr. Greaves with those tables, and had obtained a value for x varying from ·0190 to ·0594. He thought that the idea of being able to calculate the amount of evaporation might be abandoned. The lowest value he had obtained was on a warm, oppressive day. Dalton's law might be extended in this way. When the temperature of the water became lower than the temperature of the dew point, $w - d$ became a negative quantity, and E was negative. This was what occurred in practice. The moment the temperature of the water passed below the temperature of the dew point, evaporation ceased and condensation commenced on the surface of the water; and for 30° or 40° below the temperature of the dew point the same formula gave the amount of condensation. But he had found those experiments very difficult to manage. The vessel in which the water was contained was always covered with a non-conducting material; but he could never be certain whether moisture was not deposited on the outside of the vessel as well as on the surface of the water. The balances were similar to those used by analytical chemists. In one he put the weights, and in the other the vessel containing the water. He suspended a thermometer from the end of the beam, with the bulb just immersed in the water, and by noticing the time in which a fixed quantity of water evaporated he obtained the quantity of water evaporated at different temperatures. Out of doors his experiments were of a ruder character. It was insisted upon that the water in the gauge must be kept at the same temperature as the bulk of water from which evaporation was sought, and also that the water should be kept close to the edge of the vessel, so that it might get the full effect of the wind. In experiments with two vessels, in one of which the water was 3 inches below the edge, while the other was full, the evaporation from the former was 54 per cent. greater than from the other.

He had prepared a chart of the London rainfall, month by month, for sixty years, on which he had marked the maximum

and minimum periods of sun spots; but the results were of a negative character. In the "Philosophical Transactions" for 1801 would be found a Paper by Sir W. Herschell, in which the attempt was made to prove that the price of wheat in the Windsor market was influenced by the sun's spots.[1] The question had been lately revived by Mr. Meldrum, who thought that cyclones and the rainfall were influenced by the same cause. A communication had also been lately presented by Mr. Hennessey to the Royal Society, with a view to establish a connection between the rainfall at some place in India and sun spots;[2] and at the last meeting of the British Association it was argued that the amount of ozone was influenced by the same cause. His investigations led him to believe that, if the question was ever to be decided, it would not be by taking the rainfall at any one place, but by estimating it over the surface of the globe. It would be observed that in 1868–9 the rainfall at Nágpúr was 20 inches, 5 inches less than in London; while in Japan, at the same time, there was an exceptionally wet period, the amount of rain being 60 inches above any other year on record. If two independent workers had been investigating the matter at that time, one in Japan and the other in India, their conclusions would have been widely different.

Mr. Russel Aitken observed that in India the rains were affected by the smallest causes. Rocky or sandy ground, heated by the sun, kept off the clouds; but where the ground was covered with trees, the rain was much more abundant. In the island of Bombay, within a space of 3 miles the amount of rainfall differed 8 or 10 per cent. In the Western Ghauts, at Mahableshwur, the annual rainfall was 300 inches, while within 10 miles, at Panchgunny, at the same level, the rainfall was only 50 inches; so that deductions from rain-gauges should be accepted with great caution, and only be regarded as applicable to small areas. The reservoir of which he had charge, the Vehar Lake, near Bombay, was practically a rain-gauge with an area of 2 square miles; and, although the results did not exactly agree with the records of smaller ones, he thought they would be interesting to the Institution. Mr. Conybeare, M. Inst. C.E., who constructed the works,[3] calculated the supply on the assumption that the annual rainfall would be the same as at a village 5 miles distant, where it

[1] *Vide* Phil. Trans. 1801, p. 313 *et seq.*

[2] *Vide* Proceedings of the Royal Society, vol. xxii. p. 286.

[3] A description of these works will be found in the Min. of Proc. Inst. C.E., vol. xvii. pp. 555–568.

amounted to 120 inches, of which he thought 74½ inches could be secured, or $\frac{6}{10}$, being about the same proportion as was usually calculated for England. This, however, was not obtained. The area of the gathering-ground was 3,515 acres, including the lake, of 1,260 acres. The lake overflowed the waste weir about every three years. In 1865, a year of average rainfall, the total amount of water impounded was 5,650,000,000 gallons, the recorded rainfall being 89 inches. He reckoned that between 20 and 30 inches of

FIG. 1.

Million gallons.
June. July. Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May.
Feet.
LEVEL OF TOP OF STONEWORK OF WASTE-WEIR
1870
1863
1865
1871
362 356 350 344 338 332 326 320 314 308 302 296 290 284 278 272 266 260 254 248
60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40
Jan. Feb. Mar. April. May. June. July. Aug. Sept. Oct. Nov. Dec.

Height of Water in Vehar reservoir, Bombay Waterworks.

the rainfall were absorbed by the ground and evaporated by the trees during each year. This amount would only apply to a gathering-ground such as Vehar, of which the soil was soft, densely covered with trees and grass, and where the rain lasted about one hundred and twenty days on an average. In 1870, when the rainfall was 65 inches, the total amount collected in the reservoir was 4,400,000,000 gallons. This showed that about 75 per cent. of the rainfall from the gathering-ground ran into the reservoir. In 1871, when the rainfall was exceedingly deficient, namely, 39 inches, the amount was 2,040,000,000 gallons, being only 50 per cent. of the rainfall. The amount collected from the gathering-ground in tropical countries, exclusive of what fell on the reservoir, and which was of course all impounded, might vary from 85 to 50 per cent. of the rainfall, and each case must be judged from the particular circumstances by which it was surrounded. The leakage, together with the evaporation from the lake, did not exceed 5 inches per month. He calculated the leakage from the various dams at 1½ inch; so that the evaporation during the dry weather, and he thought it would be the same during the wet weather, would be about 3½ inches per month, or 3½ feet per annum; a very different quantity from the 8 feet or 9 feet with which reservoirs in hot climates had been usually credited. Fig. 1 represented the height of water, at various times, in the Vehar Lake above the Puspolee datum. The figures on the left hand represented the capacity of the reservoir in million gallons for each foot of depth; those on the right, the gauge at the Vehar Lake tower. The reservoir was completed in 1859, and overflowed in 1861, 1863, 1866, and 1869. The rainfall in 1863 was 117 inches.

Mr. GREAVES observed that the Nágpúr waterworks appeared to have been exceedingly well constructed. The extent of the gathering-ground was inconsiderable, and the reservoir was proportionately rather large. It was to be hoped, for the sake of Nágpúr, that some other gathering-ground was available; and if so, it would be well worth while to expend an additional £40,000 upon it. To have constructed such works for so small a sum was a marvellous feat. The value of the old dam was not stated; and possibly there was no expenditure on the gathering-ground. He would ask whether the latter was so placed that it was not likely to be built upon—because a village in the midst of it might pollute the whole water supply? It would be well to ascertain whether some of the ancient reservoirs, bunds, and bridges in India might not be utilised. With regard to evaporation, he had discarded the

idea of estimating it in a form applicable to engineering works by the use of wet and dry bulb thermometers, and he had contrived an instrument (which was exhibited) that would be applicable for continuous observations, and would give as useful a register of evaporation as a rain-gauge of rainfall. He agreed that gauges had hitherto been constructed on a wrong principle. They were made in a way to absorb the heat, and not so as to keep the temperature the same as that of the water. The gauge should be in a similar condition to a reservoir, pond, lake, or quiet river, and therefore would be best if consisting of a piece of the reservoir itself. The amount of evaporation in the neighbourhood of London was $\frac{4}{5}$ of the rainfall, and the question was as important as that of the rainfall. The influence of wind in promoting evaporation did not appear to have been sufficiently noticed, particularly in those countries where winds proverbially named hot were accustomed to blow. The desiccating power of those winds was, in his opinion, even greater than simple solar heat or local temperature.

Lt.-Col. A. Strange said that, though not a professional engineer, he might be allowed without presumption to bear testimony to the great care and skill with which the Paper had been drawn up. It afforded an interesting exemplification of the wide range of the duties of an engineer; for it passed, by a natural transition, from a matter-of-fact subject—that of the construction of a dam—to a subject in the region of speculative science, viz., the influence of the sun upon meteorological phenomena. It was evident that the sun was, directly or indirectly, the cause of almost every meteorological phenomenon; but hitherto, from various causes, the study of the sun had not formed a portion of the investigation of meteorologists. They appeared to have taken it for granted that, although the sun caused meteorological changes, it acted as a constant force, which might therefore be disregarded in the investigation. It was the inconstancy of the sun's action that was the question at issue. That had been studied to a certain extent, but as yet quite insufficiently. The Astronomer Royal had given an example of one mode of studying it by means of radiation experiments, which were valuable so far as they went; but they only formed a small portion of a large subject. It was natural that the sun's spots should form the first branch of the inquiry, as they were conspicuous, and underwent striking changes. As soon as it was announced, by persons of high authority, that the sun's spots were apparently periodical phenomena, going through their changes in a cycle of about eleven and a half years, it was natural that those who pursued meteorological in-

quiries should endeavour to detect a correspondence between those periods and the periods of meteorological phenomena, such as rainfall. He was not, however, one of those who accepted either the sun-spot period, or any of the uses to which it had been applied. In his opinion the observations had been quite insufficient to determine the period. They had been made with great care and by competent persons, but only in a few isolated places where there had been frequent interruptions from cloudy weather. There was nothing like an unbroken series of such observations in existence; and it was only from a continuous series that a satisfactory conclusion could be formed. The sun's spots might be of various kinds. Hitherto they had been treated as all of one kind, and the sum of their areas had been used to deduce the maximum and minimum sun-spot periods. Some, however, might be constant, while others might fluctuate. He could not admit that the sun's spots were necessarily the most efficient phenomena on the sun's surface to produce meteorological changes. They were the most conspicuous, but not necessarily on that account the most important. Before attempting to establish anything like a connection between the sun's changes and the changes on the earth, it was necessary to know the whole story with regard to the sun, and not only a small portion of it. The subject was as yet entirely in its infancy; and now that it was felt that a connection existed, though the terms of it could not be stated, it was important that the sun should really be studied with reference to that point. He was glad to find so great an interest taken in it by the members of the Institution, since it showed that the study of the subject had not only a philosophical, but a utilitarian value. He regarded it as the greatest and most difficult problem that science had now to solve, and he believed that its solution would be most fertile in its results. The study of the subject, however, would have to extend over some years, and it would not be wise to jump too readily to conclusions. What was required for the prosecution of this most pressing research was, that a number of suitable observatories should be established in localities so selected that clear weather might be expected always in one of them at least. By these means would be obtained the great desideratum of a record of the solar changes on every day throughout the year. Such a record would help to demonstrate not only that changes took place, but also how they took place—in other words, the law of the *modus operandi* might thus be detected. The great differences of climate existing in various parts of India at the same period of the year pointed to that country as peculiarly adapted by nature for such inquiries; and no

part of the British dominions was more interested than India in a knowledge of the laws which governed meteorological fluctuations —laws which, when known, would doubtless afford indications when to expect excessive or defective rainfall, so important with respect to periodical famines—as also cyclones, and other phenomena affecting health, agriculture, and navigation.

Mr. T. Ormiston said that when, seven years ago, he made an inquiry as to an auxiliary water supply for Bombay, and had occasion to examine into the question of evaporation, he applied for information to a gentleman the most competent to form an opinion, and who had experimented on the subject, Col. Fyfe, of the Royal Engineers, and Superintending Engineer for Irrigation in the Bombay Presidency. Colonel Fyfe stated that in large reservoirs —say 2 square miles in area—the amount of evaporation that he allowed for was about 3 feet per annum in the Deccan, and something less in the Concan district. From that, and from other information, he had put it down at 3 inches per month in the fair season, which lasted eight months, and half that amount in the rainy season, altogether $2\frac{1}{2}$ feet per annum. Deducting that amount, and allowing the whole rainfall on the water area of the reservoir itself, and 55 per cent. to run off the ground, would give a tolerably fair approximation of the capability of the drainage valley. He found, however, that a considerable amount was lost by soakage and leakage through the dams. That of course would depend on the materials of which the dams were made, and the care with which they were constructed, as well as on the soil on which they were placed, and on their height. Taking everything into account, he considered that by deducting $\frac{1}{3}$ from the product the remainder would be available for distribution in the town. This mode of estimating the supply available for the Bombay district was approximately correct, and it was adopted by Major Tulloch, R.E., Assoc. Inst. C.E., in his report on the water supply of Bombay generally.[1] The question of evaporation was a very complicated one, depending upon a great many circumstances, one of them being the depth of water in the lake itself. In November last year, in Bombay Harbour, the thermometer being at 104° in the sun and 81° in the shade, where the water was 22 feet deep, the thermometer 2 feet under the surface showed 79°, and when it was only 4 feet deep, at the same level under the surface, 80°. Hence it would appear that a shallow tank would evaporate more

[1] *Vide* "The Water-Supply of Bombay. Being a Report submitted to the Bench of Justices of that City." By Major H. Tulloch, R.E. 8vo. Plates and Maps. London, 1872.

than a deep one. He believed the works at Nágpúr had given the greatest satisfaction to all concerned. It might be open to question whether it would not have been more prudent to have taken the discharge pipe through the solid hill, instead of in a syphon over the bank, because, if a depression took place in the bank, it might be difficult to get at the pipe for the purpose of repairing it. There was one point to which the Author, with characteristic modesty, had not referred, namely, the closeness of the estimate with the actual cost. He had seen the estimate in an official paper, and it appeared to be within $\frac{1}{2}$ per cent. of the actual cost of the work. Mr. Binnie had placed a formidable prospect before the younger members of the profession, who, he said, must not only be prepared to make general plans, designs, and estimates, but to make working drawings and sections, and drawings of all the plant, and also to carry out the works. Judging from his own experience, it was not so difficult after all to carry out works in India. He had had the charge of ten thousand workpeople there. The foremen proved clever and competent, if only they were made to feel that they had an interest in the matter. He had found it a great pleasure to exchange the management of work in England for that in India, where there was no fear of a deputation from a Union interrupting the men in their work. In India, if a man was not satisfied, he simply walked off, and did not even ask for his pay. The moral to be drawn from the Paper was, that the Government would have done well if, instead of founding a new college at Cooper's Hill for sending out young gentlemen to India, they had selected experienced assistants from English offices to carry out important works in that country.

Mr. S. C. Homersham said that the amount (54 per cent.) lost by evaporation from the surface of the water, after it was collected in the lake or reservoir, seemed large. Another point worthy of attention was the temperature, 96° Fahr. in the river, and from 90° to 92° at 5 feet below the surface in the reservoir in warm seasons of the year. All who were connected or acquainted with works of that character knew that, even in this country, a great amount of animal life existed in surface water so impounded. Although here the maximum temperature of water in such reservoirs rarely exceeded 68° to 70° Fahr., yet in warm seasons one could not take a gallon of water from a stagnant lake, natural or artificial, without finding twelve or fourteen different species of minute animals and great numbers of each species, many of them very unwholesome; such things ought not to be found in potable water. Where lake or reservoir water

was, as in India, at a temperature of 90° and upwards, there were still more of such animals—sponges and higher organisms, including the guinea-worm, that attacked the bare legs of the water-carriers when wading in shallow water. Therefore, it was most desirable to do without surface water collected in large stagnant open reservoirs, more especially in a hot country like India, and to obtain subterranean water, which in its normal condition was uncontaminated with sewage or other organic matter, and quite free from living organisms. The amount of solid matter in the Nágpúr water was given at nearly 7 grains per gallon, one-fourth of which was put down as organic matter. This organic matter was, no doubt, mainly the residue of large numbers of animalcules; but it did not represent their entire weight. More than nine-tenths of living animalcules were water; so that when a chemist stated, as was usual, the amount of organic matter in a highly-dried state, or even burnt into charcoal from animalcules in water, that amount would have to be multiplied by ten to arrive at the weight of the animals when living. Mere chemical analysis of water, therefore, in regard to wholesomeness, might mislead; microscopical examination was also needed. The character of water had a great influence upon the health of a population, and living organisms in potable water were known to produce a large amount of disease or ill-health.

Sir George Campbell said he was not competent to discuss the scientific questions raised in the Paper: he would only remark that those who were connected with the administration of India had not been unmindful of the subject, but were doing their utmost to obtain all the scientific data possible in regard to the rainfall, the wind, and other matters. Many of the observations, it was true, were not altogether reliable; but at the large stations like Calcutta, Madras, Bombay, and Nágpúr, the various phenomena in connection with the rainfall, &c., had been observed with great scientific accuracy. He had the pleasure, before leaving Calcutta, of gratifying Mr. Blandford by arranging for a new meteorological observatory, which he hoped would be the means of adding to the valuable information already obtained. There was one point on which he had hoped that the discussion might have thrown light, viz., the possibility of storing large quantities of water under the conditions of soil and climate existing in India. That was a subject of great importance, not only in regard to the supply of water for such a town as Nágpúr, but in regard to the schemes of irrigation now before the Indian Government. The solution of the question had hardly even been approached. A

very eminent man, Sir Arthur Cotton, had suggested the possibility of enormous reservoirs for the storage of water with a view to the perennial supply of canals to irrigate the country; but the plan had not been adopted on a large scale. True, there were in India tanks of considerable size which irrigated the ground immediately under them; there were also the remains of old tanks and reservoirs constructed under native rulers; but Sir Arthur Cotton's proposal was to do things on a much more magnificent scale. None of the existing tanks would suffice to supply a large irrigation canal flowing over hundreds of miles during many months of the year. It would be desirable to know whether such things were possible. He had himself had practical reason for believing it was necessary that the question should be solved. There were irrigation works in India which depended for their supply, not upon the perennial streams of the Himalayas, but upon the surface waters of the drier parts of the interior, in such districts as those in the neighbourhood of Nágpúr. He would refer, as an illustration, to part of the scheme known as the Orissa scheme, though it did not belong to Orissa. In Midnapore, which, during the recent famine, had been affected, not to the greatest degree, but to a considerable extent, by the drought, a canal had been completed, and, shortly before the drought, had been brought into operation. Up to that time the cultivators had not been induced to take the water freely; when the drought came there was a great demand for it, but the sources were dried up, so that the demand could not be supplied. The calculations on which the canal was based failed when it came to the pinch. The canal was calculated to supply from 100,000 to 200,000 acres, but at that critical period it could not irrigate more than 30,000 acres.

General F. Cotton said there was nothing to show that there was any practical impossibility in storing water to the extent required. In the south of India the ancient inhabitants had so completely turned to account the waters of the Viga, that it was only in exceptional years that it reached the sea. This stream got its supply from the never-failing western monsoon, and, though not one of the great rivers of India, was larger than any river in England. What had been done in the valley of the Viga might be worked for in the valley of the Ganges, &c.; and, comparing the skill and appliances of English engineers with the means at the disposal of the ancient Hindoos, it was not much to say that, had the ever-flowing water from the snow of the Himalayas been turned to account by modern energy, a great portion, if not all, of the suffering and loss from the recent drought in the

Ganges valley would have been avoided. He regretted that the subject, so vast and so important, should be touched upon on an occasion when it was impossible to discuss it.

Mr. G. J. Symons remarked that the only table in the Paper to which he had any objection was that of extraordinary showers during the monsoon of 1872. With perhaps two exceptions, the showers were not such as would be considered remarkable even in this country. It was true that the rainfall at Nágpúr was only 40 inches; but remembering the few months during which that amount principally fell, he scarcely thought that the showers in question deserved the term "extraordinary." Table VI., on the other hand, was one of the finest, perhaps the finest, of the kind ever compiled. It showed that the rule often adopted in this country, that the rainfall in the wettest season was twice that in the driest, did not hold good generally, as there were several cases where the maximum was more than three times the minimum. He entirely agreed with Sir George Campbell respecting the observations made in India at the present time, but in reference to the rainfall at Madras, as far back as 1813, it was not known how the records there were then kept. Curiously enough, nearly all the exceptional features were at Madras; and this was especially noticeable in regard to the minimum and maximum fall, the latter being $4\frac{3}{4}$ times the former. The "period of observation" in Table VI. varied from nineteen to sixty years. The limits of deviation would hardly be as great in a period of nineteen years as in a period of sixty years; he had therefore tried to ascertain whether there was any relation between the "extreme range" and the "number of years;" and he found that, among the instances quoted in Table VI., there was none whatever. With regard to the relation which the average fall of the three driest consecutive years bore to the average of a long period, there had been in this country two proposals. One was to take off from the mean one-sixth, which was the same thing as saying that the average fall in three consecutive dry years was 83 per cent.; but he[1] had taken it at 80, and this, whether right or wrong, was nearest to Mr. Binnie's figures. It had been said that continuous records were desirable, and he agreed with the observation. One of the stations cited by the Author was Barbadoes. It appeared, from a recent publication by Governor Rawson, that two registers had been rolled into one, as was frequently the case. By a separate record, 77, instead of 84, was

[1] *Vide* Royal Commission on Water Supply, 1868. Minutes of Evidence, p. 38.

obtained; showing the disturbing element introduced by a register that did not run on without a break. At St. Petersburg the average of three consecutive dry years was only 64 per cent. of the mean, but those were the first years of the register, thirty or forty years ago; and he was not sure whether the records were as reliable as the subsequent ones. He concurred in all that had been said by Colonel Strange with regard to sun spots. He thought it was a pity the Author had in Tables VIII., IX., and X. departed from the excellent plan adopted in Table VI., where the rainfall was given in terms of the mean annual fall, and a series of ratio values comparable with one another, but had gone back to the old plan of giving it in inches. With regard to evaporation, the temperature of the water was taken in the experimental tank, not only at the surface and at the depth of a foot, but also at the bottom; and, moreover, a series of thermometers were placed in a river at a short distance, in order to ascertain the exact relation of the temperature of the water in the tank to that of the large mass of running water. That relation was very close indeed, but with the ordinary evaporators, in each of which observations of temperature were made, there would be differences of 20° or 30°. An anemometer was also employed within a foot of the ground, and close to the water, to determine the influence of the wind on the amount of evaporation. It had been stated that the evaporation was a certain proportion of the rainfall; this he denied. There was no relation between the evaporation and the rainfall. He might be permitted to refer the younger members to the "Annales des Ponts et Chaussées" of France, which contained records of evaporation superior to any that he had seen elsewhere. The inutility of previous methods had been discovered, and other and better means had been adopted.

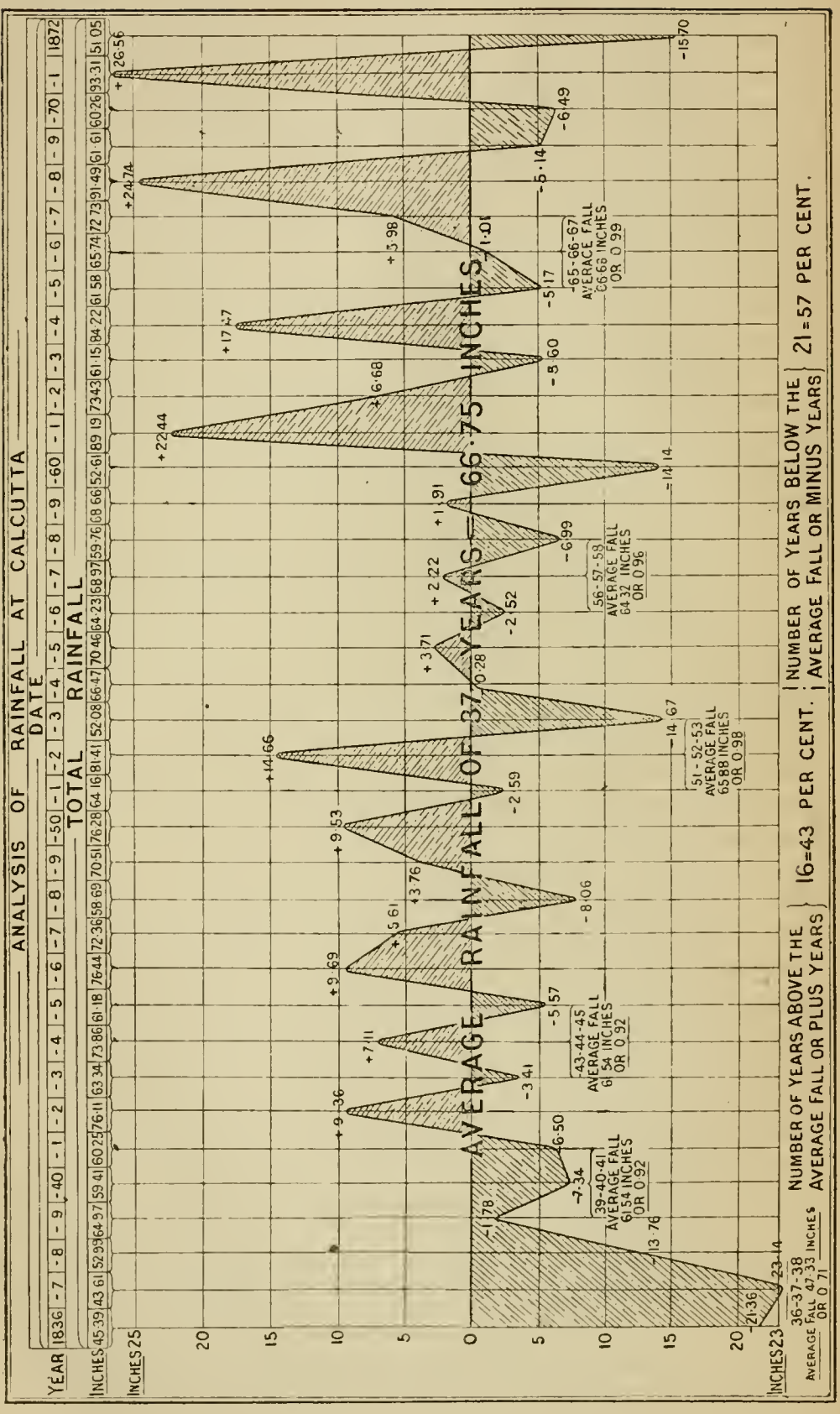
Captain Saurin Brooke, R.E., Deputy Commissioner of Jubbulpore, wished to add his testimony to the success of these works. He had found from official records that the original estimate for the Nágpúr Waterworks was £36,554; a subsequent estimate for subsidiary works, not covered by the text of the first instructions, amounted to £2,981. The expenditure, as against the original estimate, amounted to £36,718, being an excess of £164 over the estimate—somewhat less than $\frac{1}{2}$ per cent. This would be creditable in any country, and was especially so in India, where the difficulties arising from the want of trained supervision were very great, and not easy to overcome. On the supplemental estimate the expenditure amounted to £2,811, being £170

below the calculation. The net result on the two estimates was a saving of £6. The closeness of the estimate to the cost of the work would, he was sure, be duly appreciated, and was owing to the careful attention given, not only to the details of the work, but also to a rigorous supervision of the accounts. The municipality of Nágpúr might be congratulated on the successful issue of the undertaking—which was mainly due to having, under the guidance of Mr. Morris, the Chief Commissioner, selected a good man, and, without unnecessary interference, trusted him implicitly till the work was completed.

Mr. Binnie, in reply, said the value of the old embankment, considered as earthwork, and priced at the same figure as it had cost to form the newly raised portion, would be about £1,800, which would bring up the total amount to £41,332. A tunnel round the end of the embankment was not adopted on account of the expense, notwithstanding that such a mode of discharging the water would have been most advantageous. From the experience gained in constructing the works, if he were again designing them he should make the lift of the syphon considerably greater. The drainage area was a rocky, uncultivable, almost treeless and uninhabited tract. The rough grass growing during the rains was partly burned off, partly cut for thatching, and partly grazed off, but no contamination was likely to arise from the latter cause, as the dung of the animals was carefully collected by the natives for fuel. A reference to the figures in Tables III. and IV. would show that the reservoir was not too large. It contained 240,000,000 cubic feet, a little under two years' supply, which he believed was a safe capacity for reservoirs in that part of India. Nor could the drainage area be said to be too small for the size of the reservoir. On an average, during the last twenty years (as shown in Table IV.) it discharged from 60,000,000 to 80,000,000 cubic feet of water per annum more than the reservoir, as at present constructed, could contain. On a review of the whole subject, he thought it would be better if the reservoir resembled instances 5 and 6 in Table IV., and held 48,000,000 cubic feet more than at present. Mr. Homersham had selected a most unfortunate example in illustration of his favourite views. In the case of Nágpúr, the subsoil water, as obtained from wells, was often brackish. In the city of Nágpúr out of twelve hundred and thirty-one wells, nine hundred were so salt that they were totally unpotable. He could not admit that the high temperature was likely to prove so deleterious as had been suggested, or that the whole of the organic matter was necessarily

the remains of organic animal life; he believed a considerable portion of it was undeleterious vegetable matter, and, so far from the present supply affecting the health of the population, he was informed by the Sanitary Commissioner of Nágpúr that, since the introduction of the new supply, the health of the city had considerably improved. He agreed with Sir George Campbell as to the necessity for the construction of large reservoirs in India, and with General Cotton as to their perfect feasibility. Nor was it from any fault of the engineers in India that they were not constructed. Within the last few years, in a comparatively small district like that of the Central Provinces, he knew of two irrigation projects, both depending for their supply on large irrigation reservoirs. These had been sent up to the Government of India, but they were still unsanctioned. As to the showers recorded in Table II. not being extraordinary, he thought it would be impossible to cite instances in this or any other European country of showers of 3½ inches in forty-five minutes, or cases in which there had been a discharge of upwards of 90 per cent. from a drainage area of 6½ square miles within three hours after the commencement of the shower. With regard to the yield from the drainage area, taking into account that the average rainfall at Bombay was 76·8 inches, and that the climate was more humid near the sea, he thought the observations of Mr. Russel Aitken, who found the flow from the ground to vary from 50 to 80 per cent., the percentage depending on the amount of the rainfall, fully bore out his observations. For in the exceedingly dry climate of Nágpúr, with an average monsoon rainfall of only 37 inches, he had found from actual gaugings the yield would vary from 15½ up to 40 per cent., depending on whether the season's rainfall was 19 or 40 inches. The diagrams with regard to fluctuations of rainfall referred to by Mr. Bateman, of which particulars for Calcutta were given in Fig. 2, p. 56, formed the original basis on which Table VI. was constructed. They were too voluminous for publication in the Proceedings of the Institution, but he would take an early opportunity of presenting them for reference in the library. The subject of rainfall fluctuations formed the most valuable part of the Paper, and he was sorry it was not more discussed, as, in his opinion, Table VI. showed some slight approach to a general law on the subject. With regard to the exceptional character of Madras, it might be explained in this way. Throughout India rains were generally due either to the north-east or the south-west monsoon. In ordinary years Madras received its rain from the north-east monsoon, but occasionally it got a little of the south-west, and sometimes

FIG. 2.


ANALYSIS OF RAINFALL AT CALCUTTA
DATE
YEAR 1836 -7 -8 -9 -40 -1 -2 -3 -4 -5 -6 -7 -8 -9 -50 -1 -2 -3 -4 -5 -6 -7 -8 -9 -60 -1 -2 -3 -4 -5 -6 -7 -8 -9 -70 -1 1872
INCHES 45 39 43 61 52 93 64 97 59 41 60 25 76 11 63 34 73 86 61 18 76 44 72 36 58 69 70 51 76 28 64 16 81 41 52 08 66 47 70 46 64 23 68 97 59 76 68 66 52 61 89 19 73 43 61 15 84 22 61 58 65 74 72 73 91 49 61 61 60 26 93 31 51 05
TOTAL RAINFALL
INCHES 25
AVERAGE RAINFALL OF 37 YEARS = 66·75 INCHES
+9·36
-1·78
-7·34
-13·76
-21·36
-3·41
+7·11
+9·69
-5·57
+5·61
+3·76
-8·06
+9·53
-2·59
+14·66
-14·67
+3·71
-0·28
+2·22
-2·52
+1·91
-6·99
+22·44
+16·68
+17·27
-8·60
+3·98
-5·17
+24·74
-5·14
-6·49
-15·70
+26·56
-1·01
-14·14
39-40-41 AVERAGE FALL 61·54 INCHES OR 0·92
43-44-45 AVERAGE FALL 61·54 INCHES OR 0·92
51-52-53 AVERAGE FALL 65·88 INCHES OR 0·98
56-57-59 AVERAGE FALL 64·32 INCHES OR 0·96
65-66-67 AVERAGE FALL 66·66 INCHES OR 0·99
INCHES 23
36-37-38 AVERAGE FALL 47·33 INCHES OR 0·71
NUMBER OF YEARS ABOVE THE AVERAGE FALL OR PLUS YEARS } 16=43 PER CENT.
NUMBER OF YEARS BELOW THE AVERAGE FALL OR MINUS YEARS } 21=57 PER CENT.

a large quantity was blown across the continent of India. To that cause he attributed the great fluctuation between the extreme minimum and the extreme maximum which Madras presented when contrasted with other places in India. The subject of evaporation had proved more interesting than he could have expected. The observations recorded in Table V. had been made without any preconcerted theoretical views. The facts were collected in the first five columns, and thus he endeavoured to deduce from them the actual amount of evaporation. The result of the discussion proved how little was known on the subject, and how much the most eminent authorities differed as to the formulæ, and as to the coefficients to be employed. Some gentlemen were able to reconcile the first three of the observations with theory, but failed to do so with regard to the four last, while others said exactly the reverse. All however, were agreed that some great and unexplained force was at work during one of the two periods into which the table could be divided. He did not profess to give all the data on which the theory of the subject depended, but he thought he could explain the matter. From about the middle or the end of March to the commencement of the rains in June, the hot winds blew at Nágpúr continuously, during the day, with a velocity of upwards of 150 miles per day. Their temperature averaged about 98°, and the comparative humidity of the air during that time was considerably under ·50, saturation being considered as 1. Of course, in judging of hot winds according to their scientific aspect, personal feeling must be set aside, but the effect on the ordinary senses, when stepping out from a cool room on to a verandah in the open air, was something like that experienced on going in front of a blast furnace. With regard to the apparent discrepancy between the first and last results in Table V., pointed out by Dr. Pole, it might be explained in this way. As stated in the Paper, during the dry season when his observations were taken, there was a fall of 3 inches of rain, which, in order to arrive at the average evaporation per diem, he had distributed over the whole season. Out of that quantity 1·40 inch fell during the period of the last observation, from the 7th of May to the 9th of June. Taking the 1·40 inch, and restricting it purely to that one observation, not distributing it over the whole series, it raised the amount of evaporation during that period from ·0157 foot to ·019 foot per day. Remembering how many circumstances entered into the consideration of the subject, such as the temperature of the air, the dew point, the force of the wind, the elastic force of vapour,

the temperature and depth of the water, and other points mentioned during the discussion, he thought the time had arrived when, if the subject was to be thoroughly investigated, it would be necessary to give up observations with small vessels, such as those to which reference had been made; they were too shallow for reliable results as to temperature, too limited in area to allow free play to the wind, and were altogether so small as to be affected by many disturbing causes. He had endeavoured, however imperfectly, to indicate, by the facts given in Table II., how, in his opinion, the observations should in future be conducted, and he believed that his own observations, extending over a water area of 350 acres, were much less liable to small errors and disturbing causes than in the case of the 36 square feet referred to by Mr. Field. No consideration of the subject of rainfall in the present day would be complete without mention of the sun-spot theory; and he was much pleased that so free and full an expression of opinion on the subject had been elicited. The knowledge that, by his remarks, so eminent a man as the Astronomer Royal had been led to consider the relation between solar radiation and rainfall was of itself a sufficient reward for bringing the subject before the Institution. With regard to the duties of engineers in India, he had stated, to the best of his ability, his own personal experience, and what he had himself seen in the case of engineers similarly situated. Mr. Ormiston, at Bombay, was differently circumstanced. He had contractors and a large trained staff, and could obtain easily and cheaply from Europe any materials he might require. If he were removed 500 miles inland, he would be thrown much more upon his own resources. While generally agreeing in the observations as to Cooper's Hill College, yet he had no hesitation in expressing his belief that it was the finest theoretical engineering school he had ever seen, and he believed that Government would in time see the necessity of enlarging the period to be spent by the students on actual works of construction under some eminent civil engineer. Experience was at the very root of the profession, and it could only be properly acquired on actual works under a good master. Personally, he was deeply indebted to Mr. Bateman for the training he had received: without it he never could have brought this Paper properly before the Institution, and he was sure that training could not have been received at any school or college, however good.

Mr. Harrison, President, said the manner in which Mr. Binnie's observations had been received rendered it unnecessary for him to say a word as to the value of the Paper. It had been the

means of laying before the Institution matters of considerable interest, and had brought among them their Honorary Member, the Astronomer Royal, who had propounded, not exactly a theory, but a striking coincidence in regard to the rainfall going *pari passu* with the heat of the sun. Although he called it merely a coincidence, he was about to devote his attention to the matter, to see whether there was anything in it that could be reduced to a positive theory. He could not allow the opportunity to pass without making a remark on a further coincidence, in regard to the works constructed by Mr. Binnie. That he should have submitted an estimate for a large work of that kind, and actually completed it within a few pounds of that estimate, was a circumstance that reflected upon him the greatest credit, and he only wished that in the numerous works executed in this country, engineers could lay claim to similar accuracy. He had not himself been engaged in the construction of reservoirs of anything like the magnitude referred to. Immense reservoirs and embankments, however, had been constructed in England, and if it could be shown that such enormous receptacles for water as had been alluded to were a matter of necessity in India, he believed the practical ingenuity, talent, and experience of engineers would not be wanting for carrying them out.

Mr. Henry F. Blanford remarked, through the Secretary, that, in his opinion, India offered a fairer field for investigating the perplexed problem of rainfall, and, indeed, most other meteorological conditions, than any country equally accessible; and he hoped that the steps now being taken by the Indian government to systematise observation and to render the results accessible, would, in the course of a few years, lead to definite conclusions on the subject. He would add a few data to those given by the Author.

With respect to Calcutta, the recorded rainfall from 1829 to 1835 was as follows:—

	Inches.		Inches.
1829	59·94	1833	60·56
1830	63·28	1834	68·73
1831	56·90	1835	85·50
1832	50·72		

and that of 1873, not included in the table, was 45·27 inches. The average of the forty-five years was 65·44 inches, which differed but little from that of thirty-seven years given by the Author. The largest fall recorded within twenty-four hours was 12 inches. That quantity fell on the 11th of May, 1835, and

again on the 13th of June, 1861. On the former occasion the whole fall took place in three hours.

The average rainfall of Nágpúr, according to his data (twenty-four years), was somewhat higher than that given by Mr. Binnie; it was—

	Inches.
From January to May	3·22
,, June to September	38·42
,, October to December. . . .	3·70
	45·34

The following data for the seven years, 1826–32, were given by Dr. Buist, in his "Manual of Physical Research for India":—

	Inches.		Inches.
1826	65·16	1830	33·00
1827	53·99	1831	65·31
1828	46·61	1832	37·14
1829	50·25		

Nothing was stated with respect to the position or character of the gauge used in these measurements; perhaps, therefore, the returns could not be accepted with perfect confidence. The average of these years, distributed according to the seasons as above, was—

	Inches.
From January to May	3·14
,, June to September	40·12
,, October to December. . . .	5·63

It was to be noticed that the high average of the last three months of the year was chiefly affected by the large quantity of 17·75 inches recorded in 1831, of which 8·24 inches fell in the month of December alone.

He did not think that at present any light could be thrown on the causes of the fluctuation of the rainfall in different years, and as yet no empirical law of any value had been discovered in its irregular incidence. But there seemed to be some prospect that the study of the distribution of pressure in the monsoon region would, in the course of time, throw some light on this perplexed subject. In a Paper communicated to the British Association this year, at Belfast, he showed that, as appeared from the barometric registers of the last six years, the irregularities of relative pressure in Northern India, regarded as deviations from the normal or average distribution of pressure for a given month or season, were frequently protracted, so that the same abnormal features of pressure-distribution frequently lasted through a whole monsoon;

sometimes, indeed, it would appear from the registers, through one or two years; but this required further verification. Moreover, in one or two cases, notably in the monsoon of 1868, and less distinctly in that of 1873, there appeared to be a definite relation between the position of the abnormal barometric depression and that of excessive and deficient rainfall respectively. Unfortunately, most of the barometric registers kept in India, till within the last few years, were worthless, the observations not having been corrected to any standard, and observers having neglected to ascertain the elevation of their instruments above sea-level, or any local datum level; so that it would require several years' observations to work out the laws suggested by the facts recently observed. As far as could be surmised at present, it seemed that it was at least as probable that deficient rainfall in one region was compensated by excessive rainfall elsewhere, as that the observed irregularities were general and simultaneous. At all events it would, he thought, be a mistake to direct attention too exclusively to the question of cycles, and to neglect inquiry into that of compensating areas, which to him seemed the more promising of the two. The monsoon region of South-Eastern Asia presented many advantages for such an inquiry, as it was (in India at least) cut off from Central Asia by the Himalayan chain, and had an independent wind system. It was to be hoped that systematised observation in India might lead to some more definite conclusions than had yet been attained.

With respect to an observation of the Astronomer Royal as to the apparent concurrence of increased solar radiation at the earth's surface, with increased rainfall, the Indian observations showed that the temperature of solar radiation was the higher, the drier the atmosphere and the smaller the rainfall.

November 17, 1874.

THOS. E. HARRISON, President,
in the Chair.

The discussion upon the Paper, No. 1,398, "The Nágpúr Waterworks," by Mr. BINNIE, was continued throughout the evening.

November 24, 1874.

THOS. E. HARRISON, President,
in the Chair.

No. 1,332.—"The Pennsylvania Railroad; with remarks on American Railway Construction and Management."[1] By CHARLES DOUGLAS FOX and FRANCIS FOX, MM. Inst. C.E.

THE main line of the Pennsylvania railroad, of which alone a detailed description is given in this communication, extends from Philadelphia to Pittsburgh, a distance of 355 miles; of this distance a length of nearly 354 miles is double line. In direct connection with the main line, and worked with it, are 82 miles of single branch lines and 230 miles of sidings. The trunk line traverses a densely populated country, and brings Philadelphia (and through its connections also the city of New York) and the eastern seaboard into direct communication with the richest parts of the state of Pennsylvania, the immense coalfields of Pittsburgh and the vicinity, and the Western system of railroads. The Pennsylvania Railroad Company has, however, extended the boundaries of its system, until it now controls, either by leases, working agreements, or otherwise, an additional length of 5,088 miles of railroad (chiefly single lines), and 408 miles of canal, giving two independent through routes to each of the cities of Cincinnati, Chicago, and St. Louis, and placing the company in a very advantageous position in most parts of the West.

The following statistics are taken, partly from a most exhaustive report,[2] issued in the present year by an "Investigating Committee" of the shareholders, acting in concurrence with the directors, and partly from special reports kindly prepared for the Authors by the officers of the company.

The capital account of this great system of 5,933 miles of railroad and canal, up to the end of 1873, shows an expenditure of

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

[2] *Vide* "Report of the Investigating Committee of the Pennsylvania Railroad Company." 8vo. Philadelphia, 1874.

£73,015,740, or £12,300 per mile, and the results of the working for that year, were as follows :—

	£.	Per mile per week. £. s. d.	
Receipts. . . .	15,223,067	= 49 7 0	
Expenses . . .	10,552,412	= 34 4 0	= 69⅓ per cent. of the receipts.
Net earnings . .	4,669,004	= 15 2 8	= 6·4 per cent. per annum on the whole capital, including bonded debt.

The capital account of the main line, with its branches, representing a total length of 791 miles of single line, exclusive of sidings, shows a total expenditure of £8,904,830, or £11,250 per mile of single line, thus approximately divided, viz. :—

	£.
Land for railroad and stations, per mile	2,500
General works, permanent way, and stations, per mile . . .	5,250
Locomotives and rolling stock, per mile	3,500

In order, however, to arrive at a fair estimate of the total cost, it is necessary to take into account the fact that the company, pursuing in this respect an unusual, but, as the Authors submit, a very wise course, long since closed the capital account for the main line, and that, exclusive of ordinary maintenance and repairs, there has been expended, out of revenue, during the years 1855 to 1873 inclusive, upon permanent improvements and works of construction, including the substitution of iron for wood in bridges, and of steel for iron rails, no less a sum than £5,310,227, or £6,713 per mile, bringing the cost up to £17,963 per mile of single line. If, in the absence of separate accounts, there be deducted for the branches, 82 miles at the average cost of American railroads, viz., £9,820 per mile, the cost of the main line will be found to be about £37,827 per mile of double line.

The company originally purchased land at each of the chief centres, much in excess of the then immediate requirements of the line, and the wisdom of this course is manifest, not only from the great facilities thus afforded for the vast traffic which has grown up, but from the fact that this land, which originally cost £1,184,169, is now worth, at a low valuation, and after excluding that occupied by the railroad itself, the sum of £3,401,937, or very nearly three times its cost.

Table I. in the Appendix gives the results of the working of the main line and branches for a period of thirteen years. The net earnings have been, on the average, a little over 12 per cent. on the capital. From 1853 to 1873 the company have paid an average dividend of 9·9 per cent., and a total amount in dividends equal to 234 per cent. upon the entire capital cost.

The following are the receipts and expenses for the year 1873, compared with those for the same year on the railways of the United Kingdom :—

	Pennsylvania railroad.	United Kingdom.
	s. *d.*	*s.* *d.*
Gross receipts per train mile	5 $6\frac{1}{2}$	5 10
Expenditure per train mile thus divided, viz.:		
Maintenance of works and permanent way	0 $8\frac{3}{4}$	0 $7\frac{1}{4}$
Locomotive power	0 $11\frac{1}{2}$	0 11
Carriages and wagons	0 $5\frac{1}{4}$	0 3
Traffic charges	0 $15\frac{1}{2}$	0 $10\frac{1}{4}$
Miscellaneous	0 $1\frac{1}{4}$	0 6
= 62 per cent. of gross receipts	3 $6\frac{1}{4}$	
= 53 per cent. of gross receipts		3 $1\frac{1}{2}$

A comparison of the results in 1872 would be more favourable to English railways, the proportions of expenses and gross receipts in that year having been—

	Per cent.
On the Pennsylvania railroad	63
On the railways of the United Kingdom	49

An analysis of the traffic on the main line in 1873 gives the following results :—

	d.
Receipts per passenger per mile	1·1
Expenses „ „	·9
Net earnings „ „	·2
Receipts for goods per ton per mile	·6
Expenses „ „	·33
Net earnings „ „	·25

Table II. in the Appendix gives particulars of the work done by the locomotives on this line over a series of years.

Table III. is a statement of the locomotives and rolling stock belonging to the company over a series of years.

Table IV. in the Appendix gives a comparative statement of the locomotives and rolling stock of the United States, the United Kingdom, and India in 1873.

The earthworks of the main line are heavy in many parts; and the inclines carrying the railroad over the Allegheny Mountains, although the gradients are moderate in comparison with those on other passes, are amongst the most important in America. Starting in Philadelphia from almost the sea level, the line rapidly rises, in the first 8 miles, to a height of 350 feet. This elevation is gradually increased to 1,170 feet at Altoona, 237 miles from Philadelphia, where the mountain incline commences; and between

Altoona and the summit at Gallitzin, 249 miles from Philadelphia, which is 2,154 feet above the sea, there is a total rise of 984 feet in 12 miles, the average gradient being 1 in 82, the maximum 1 in 55. From the summit the line rapidly falls to 1,170 feet above the sea in 25 miles, and thence descends to Pittsburgh, 720 feet above the sea, at 355 miles from Philadelphia.

The sharpest curve (except on the Philadelphia division) has a radius of 716 feet, and out of 250 miles of line 10 miles are on curves of a less radius than 1,000 feet. Between Philadelphia and Harrisburgh the line was laid out originally with sharper curves; but extensive deviation works have now been completed throughout this section, involving almost an entirely new railroad.

In the Appendix (Tables V. and VI.) details are given of the curves and gradients.

The gauge of the line is 4 feet 9 inches, and the width at formation level, on embankment, is 24 feet 3 inches, made up as follows:—

	ft.	ins.
Between rails	7	0
Two lines of rails, 4 feet 9 inches each	9	6
Sleepers, 1 foot 10½ inches outside rail	3	9
Ballast, 1 foot outside sleeper	2	0
Formation outside ballast	2	0
	24	3

In cuttings in ordinary soil the width is 32 feet, and in rock 28 feet, thus giving ample width for drainage. The usual slopes in cuttings are, ¼ to 1 in rock, 1 to 1 in ordinary soil, and in embankments 1½ to 1.

As is general in America, there are few over-bridges, almost all the public roads being carried across the line on the level. Gates are seldom erected, the line being protected by a simple guard, and by notice boards in conspicuous positions across the carriage road. This plan, combined with a large bell on the locomotive, which warns the public, but does not frighten horses, answers well, even where there is considerable traffic on both road and railroad. It is economical in first cost, and also saves the salary of a gateman at each crossing in perpetuity. In some of the latest locomotives, the bell is moved by a rod from the eccentric strap, and is kept continually ringing. There are, however, numerous bridges for carrying the railroad over streams. In the Appendix (Table VII.) a statement is given of the principal bridges on the main line, of an aggregate length of about 3 miles. The abutments and piers are generally of substantial masonry,

either rough-dressed ashlar, or coursed rubble. The timber structures, erected in the first instance, are being replaced by stone and iron. As a rule, the bridges have the railroad on the top, and are composed of three main trusses of the lattice form of construction. The Coatesville bridge, of six spans of 125 feet each, has lattice girders with vertical struts of cast iron, diagonal braces of bars, and a lower chord of rolled links connected with the struts and ties by bolts, which extend the whole width of the bridge. These, with an elaborate system of longitudinal, vertical, and diagonal cross bracing, stiffen the structure in every direction. The cross girders, which are of timber, rest upon the upper members of the girders, there being one over each strut, and two intermediates to each bay, thus bringing cross strains upon the upper members between the verticals. In the Mount Union bridge, of five spans of 121 feet 6 inches each, the trusses are constructed upon the stiffened triangular system (Plate 4). The truss is divided into bays of equal length and depth, viz., about 15 feet, with vertical struts of wrought iron, stiffened with distance pieces and cross bracing. The top member is composed of two external channel irons and two bulb irons inside, connected at the top by plates. The bottom chord consists of rolled links, and the chief connections are effected by pins. The diagonals are each formed of two wrought-iron bars, stiffened by distance pieces and bracing. To support the upper member and convey the strains more directly to the abutment, a short strut, composed of two channel irons, with distance pieces, is inserted in the middle of each bay. This strut connects the diagonal with the top flange, the point of junction of the strut with the diagonal being again tied to the adjoining vertical in the direction of the middle of the bridge. This plan appears advantageous, when, as in this case, the cross girders are intermediate between the main points of support, the wooden beams forming the cross girders having their centres only about 2 feet apart, and seven of them thus being intermediate in each bay. The bridge over the Susquehanna river, of twenty-three spans of 154 feet, and a total length of 3,680 feet, is for a single line, and is the only bridge on the main line with a wooden superstructure, the trusses being on the "Howe" system with arches, but not calling for special remark.[1]

There are eight tunnels of the aggregate length of 2,646 yards, the longest being 1,204 yards.

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[1] *Vide* "American Timber Bridges," by J. R. Mosse, M. Inst. C.E., and "American Iron Bridges," by Zerah Colburn. Minutes of Proceedings Inst. C.E., vol. xxii., pp. 305 and 540.

The permanent way or track on the main line is of unusual strength for an American railroad. The standard section of rail (Plate 4) now used weighs 67 lbs. per yard, and is of steel, $4\frac{1}{2}$ inches high with a base only 4 inches wide, which appears very narrow for a rail of this weight. The fishplates or splices are 24 inches long, $2\frac{45}{64}$ inches deep, and $\frac{1}{2}$ inch thick, fastened with four bolts $\frac{3}{4}$ inch diameter. The sleepers or cross-ties are of white oak $8\frac{1}{2}$ feet long, and 8 inches by 8 inches in section, and are spaced 48 to every 100 feet, or 2,534 to the mile. There is no joint sleeper, the rails being laid to break joint, and the joints suspended. The rails are secured to the sleepers by dog-spikes, but these do not draw easily from the hard wood sleepers. Fang bolts are not used, being exceedingly inconvenient, for when the road bed is frozen no ordinary packing can be done, and the rails have to be kept in line and level by 'shimming,' or packing with pieces of hard wood between the rail and the sleeper.

Upon the branch lines the rails vary in weight, according to traffic, from 64 lbs. and 67 lbs. for iron, to 56 lbs. and 65 lbs. for steel. Here also a wooden block is often substituted for the fishplate on the outside.

The line, contrary to general American usage, is well ballasted, in a great measure with rock. The quantity of ballast per mile of double line averages 5,200 cubic yards. The number of men employed in keeping the permanent way in repair averages two per mile of double track.

No general system of signals is used, and even indicator signals are uncommon. The old form of sliding rail is almost universally adopted in lieu of the switch, being less liable to be blocked by snow or ice. The traffic is regulated by telegraph, extensive sidings being provided for shunting purposes.

The stations are chiefly of timber, of simple and economical construction. The platforms are rarely raised, the surface of the ground being planked in the better class of stations. At Altoona and Philadelphia there are extensive shops for locomotive and carriage repairs, the carriage shops being very complete.

The different classes of locomotives are designated by the first seven letters of the alphabet (Appendix, Table VIII.); but there are in reality only three well-marked types, viz.: The eight wheel, the ten wheel, and the 'shifter' or shunting engine. The leading dimensions of the several types are given in the Appendix, and are shown in Plates 5 and 6. Only a short description of their special uses and some details will therefore be necessary. The "A" engine is the leading passenger locomotive over the

middle and Philadelphia sections of the line, and exists in three varieties, only slightly differing. The "B" engine, a small class, is used as a 'pilot' on the mountain incline. The "C" engine is almost identical with the "B," and is the most efficient passenger locomotive. One of these engines, assisted by a "B" engine, has regularly taken a train of seven passenger cars, of a total weight of 165 tons, in twenty-four minutes from Altoona to the top of the mountain. Whilst ascending the mountain with a train of nine cars, weighing 215 tons, one of these engines has evaporated 2,400 gallons of water in less than an hour. One of the "E" engines, which are chiefly used on the mountain, has taken a gross load of 223 tons (exclusive of engine and tender) up the mountain in thirty-five minutes. The "F" engine is for shunting purposes, and is called a 'shifter.' The "G" engine is for ballasting and branch traffic.

The greatest importance is attached to interchangeability of parts. An idea may be formed of the uniformity existing amongst the several types from the fact, that whilst 112 patterns are required for one engine, only 187 are required to include all the seven classes, exclusive of the tender, which is alike for all.

The locomotives have leading trucks of the variety known as the 'swing centre,' in which the socket for the centre pin or pivot of the engine, instead of being rigid, as in the old-fashioned American truck, is suspended on links, combined with a double system of springs, and is thus capable of lateral motion, allowing the centre line of the engine, when passing round a curve, to lie outside the centre of the truck. With the aid of this contrivance, the engines pass round a curve of 350-feet radius without serious strain either to themselves or to the permanent way. The lateral motion also reduces the severity of the concussion between the leading flanges and the guard-rails and crossings.

The trucks have chilled cast-iron wheels. Steel wheels have been tried, but it was found that they would not bear the severe work of guiding the locomotive over the sinuosities of the line. Solid cast wheels, with the running surface chilled, are the safest, especially in cold weather, a truck wheel of this kind rarely breaking, and one such wheel outliving at least three steel wheels. Again, the flanges of chilled wheels are soon made smooth and highly polished by wear; whilst the flanges of steel wheels become rough and torn, and in a short time too thin and sharp for safety. Chilled cast-iron wheels are also almost exclusively used for the rolling stock, steel tires having been tried for the passenger cars, but having quickly become dangerous from rapid wear. The weight

of a cast-iron wheel for a passenger car is usually 525 lbs.; it costs about £4 sterling, and has an average life of at least 100,000 miles, except when reduced by the constant use of the breaks. The metal is charcoal iron, having a tensile strength sometimes reaching 18 tons per square inch, and averaging nearly 14 tons. The driving wheels are of cast iron, with hollow spokes, usually counterbalanced with lead. They are fitted with steel tires, except for shunting engines, where chilled tires are more durable, having to perform the duty of guiding as well as driving. Steel tires are held in high estimation for driving wheels, and the desire to use them wherever possible has exercised a controlling influence over the designs of the engines. As an engine could not be guided, as before stated, by steel flanges, the driving wheels have been placed far enough back from the cylinders to allow the whole duty of leading to be performed by the truck. Efforts have been made to render the weight of the forward part of the engines available for tractive purposes, by throwing the driving wheels farther forward; but these failed, for the reasons already given, unless chilled tires were used, which are themselves a source of trouble, and are avoided except for shunting engines. Although they do not break, they become flat and loose.

The boilers (Plate 6) are of soft crucible steel, the shell of the larger ones being $\frac{3}{8}$ inch, and of the rest $\frac{5}{16}$ inch thick. The fire-box is also generally of steel, $\frac{1}{4}$ inch thick, with the exception of the tube-plate, which is $\frac{7}{16}$ inch thick. Sometimes, however, the tube-plate is made of copper $\frac{3}{4}$ inch thick. The tubes are invariably of iron, No. 11 gauge. A sample of every plate of steel used in the construction of a boiler is tested by being heated to redness, and then plunged into cold water; after which the same piece, while cold, is bent double and hammered flat. The tensile strength of some of the steel, which is made at Pittsburgh, is 90,000 lbs. per square inch. The majority of the boilers have a combustion chamber from 4 inches to 6 inches long, so as to avoid exposing the thick metal of the tube-sheet to the direct action of the fire. The whole strain on the top of the fire-box is borne by the crown bars, and is thence transmitted through the sides to the bottom ring. This practice, adopted several years ago, is considered safer for steel, but not for copper fire-boxes, than the old custom of connecting the crown of the fire-box by braces with the roof of the boiler. Many explosions are due to these braces, but their omission has not led to a single explosion. The furnaces are supplied with water grates, consisting of pipes $1\frac{7}{8}$ inch outside diameter, placed $3\frac{1}{2}\frac{1}{0}$ inches apart from centre to centre. The grates have been in use for a long time,

and outlast the furnace, if kept free from mud. As they are very open, it is rarely necessary to stir the fire. The deflector is composed of large fire-bricks resting on the water-pipes and extending from the throat-sheet to the crown. The feedwater is supplied by one injector and one pump. In addition to the tires and boilers, crucible steel is employed in the locomotives for such parts as guides, crank pins, connecting rods, and axles.

As is usual throughout America, the locomotives are provided with massive cabs having double roofs and luxurious seats. The driver almost always sits to his work, and the regulator and reversing gear are arranged accordingly. To prevent unnecessary exposure of the men to the weather, most of the lubrication is done from the foot-plate. Plain hose couplings between engine and tender are found less liable to get out of order in frosty weather than the ball-and-socket joint; and where the water-pipes are exposed there is a contrivance for blowing a jet of steam into them. Communication is effected between the driver and the conductor and passengers by a cord running inside the cars along the roof within easy reach, and connected with a gong under the cab or with the whistle. The head lamps are of large size, with powerful reflectors, so as to illumine the track for a considerable distance in front of the train, and, in combination with the bell and whistle, to frighten straying cattle off the line.

The passenger cars, including sleeping cars, compartment, vestibule, parlour, drawing-room, and "silver-palace" cars, "all of which are the result of a pressing necessity for the invention of new superlatives of excellence, many of the public being too nice to travel simply first class," resemble those on the best railroads of the States, of which descriptions have been already given to the Institution.[1] The weight of an ordinary car is 17 tons, and, as it will accommodate fifty-two passengers, there is a dead weight of $6\frac{1}{2}$ cwt. to each passenger. The weight of an old-fashioned sleeping car is 20 tons, of a "Pullman palace car" 26 tons; and, although each is provided with twenty-four double berths, and could therefore carry forty-eight persons, in practice it is of rare occurrence for a berth to be occupied by more than one person; thus reducing the passengers to twenty-four, and giving a dead weight, in one case of 17 cwt., and in the other of $21\frac{3}{4}$ cwt. to each passenger. The mileage of these special cars is about 120,000 each per annum. The Pullman Palace Car Company run on this railroad alone one hundred and seventy cars, costing on the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 360.

average £3,000 each, or a total of £510,000, and upon their capital the Pullman Company earn about 12 per cent. It is much debated amongst practical men in the States whether the incidental gain to the companies from the use of these unwieldy, though comfortable, vehicles compensates for the cost of haulage of such an excessive amount of dead weight, and for the increased cost of maintenance of the permanent way. The Investigating Committee, in their report, stated, on the one hand, that these cars were "most valuable, and even indispensable in the present state of public feeling in America," but, on the other hand, that they were "very heavy and track-destroying;" they also considered that the railroad company did not receive enough for the running of the cars, getting as it did only the ordinary fares, and the Pullman Company receiving all the advantage of the additional sums charged. Part of the stock accompanying passenger trains consists of cars for parcels and light freight run by the Express companies, who have the monopoly of such traffic on many of the lines, and of the combined mail and baggage wagons, which are about 30 feet long. The passenger stock is all fitted with bogie trucks admitting of lateral play. The ordinary passenger cars have two pairs of chilled wheels on each bogie, and the weight of the truck is 6,400 lbs. The "sleeping" and "palace" cars have six wheels to each bogie, and the weight of the truck is 9,600 lbs.

The axles are of soft crucible steel, and are required to stand the following test, viz.:—Out of every lot of fifty axles one is taken at random, and placed on bearings 3 feet apart. It is then exposed to blows in the centre from a weight of 1,640 lbs., falling 25 feet; and, to be accepted, the sample axle must bear five blows without breaking. To show their quality, on the 15th of November, 1867, an axle was only broken after fourteen blows, of which three were from a height of 35 feet, one from 36 feet, two from 38 feet, seven from 39 feet, and the last from 40 feet, the axle being turned over at each blow. The axles are of English make, rough-turned, of 4 inches diameter in the middle, increasing to $4\frac{3}{4}$ inches in the wheel. The journals are $3\frac{1}{4}$ inches by 7 inches. In an ordinary passenger car each journal has to carry 4,000 lbs. of dead weight, and a maximum of 1,000 lbs. of live load, whilst the total load on each journal of a palace car is about 600 lbs. less.

The cars are lighted by ordinary coal gas, compressed to about 300 lbs. per square inch, in tanks under the body of the car. Enough gas is carried to supply one burner consuming 3 cubic feet, and four burners consuming 6 cubic feet per hour during twelve hours. Heat is supplied by a stove at each end, burning an-

thracite coal, and so arranged that a current of air is forced into the stove by the motion of the train. After being warmed, the air is distributed by passages under the seats.

The Westinghouse pneumatic continuous break, now being introduced into English rolling stock, has been in general use on this railroad for several years. It gives the engine-driver unfailing control of the train, and enables him in an emergency, by turning a small handle, to put the breaks on every wheel, including in some cases those of the locomotive, commencing at the rear of the train. He is thus able to stop a passenger train when travelling at a speed of 30 miles an hour down an incline of 1 in 60, in a distance of less than 500 feet. The details of this break are now generally known, but the following description may be of interest:—A double-acting steam cylinder, with double-acting air pump attached, is placed in a vertical position between the driving wheels of the locomotive, and fastened to the frame with the cylinder and barrel in the same axial line. The action is direct, the steam and air pistons being fixed to the same rod. The air, when compressed, is stored in a reservoir constructed of boiler plate beneath the foot plate, a gauge being placed within view of the driver to indicate the pressure. To the underframe of each car an ordinary cylinder, fitted with a piston and a piston rod, is connected by an adjustable slotted head with the break lever in such a way that, when compressed air is admitted into the cylinder, the breaks are put on. From a point near the opposite end of the cylinder a pipe makes a T connection with an air pipe extending the whole length of the car. This has, at each end, a flexible coupling to connect the pipes from the cars with a similar pipe from the reservoir. By means of a three-way cock, the engineman can turn air into the cylinders and thus put on the break; or he can open communication with the outer air, relieve the pressure, and thus take off the breaks, which are then kept clear of the wheels by springs. The flexible couplings can be rapidly connected or disconnected; they are fitted with two valves, the spindles of which are long enough to unseat or open the opposite valve when the coupling is made. These valves are so arranged that the pressure of the air will at once close them should the coupling be broken. The break is therefore a safety one, to the extent that, if the pressure is once put on by the driver, the breaks will remain on should the train be entirely disconnected. It has lately been improved by the addition of a reservoir of pressure under each car, which is automatically brought into action in case the cars are accidentally detached. It also works well in all temperatures, and is not liable to get out of order. It is applied

almost instantaneously to all the vehicles, and, whilst the driver can, by a simple movement, apply its utmost power, he can never use such force as to injure anything, or even to skid the wheels.

The goods wagons or freight cars are of five kinds (Plate 7).

1. The 'drop-bottom coal car' is used for coal, ore, and other kindred substances, and discharges its contents without shovelling. The cars are 22 feet long by 8 feet wide; their weight, when empty, is 16,000 lbs., and each can carry from 20,000 to 24,000 lbs.

2. The 'drop-bottom gondola car' conveys miscellaneous freight, chiefly coals and timber. It is 30 feet long, by 8 feet wide, weighs from 18,000 to 19,000 lbs., and is capable of carrying a load of from 20,000 to 24,000 lbs.

3. The 'gondola' is similar to the last-named car, with the exception of having no trap doors. Its weight is about 17,000 lbs., and its load from 20,000 to 24,000 lbs.

4. The 'stock' or 'cattle' car is 30 feet long, by 9 feet wide, weighs about 19,000 lbs., and can carry 16,000 lbs. loaded with horses; 14,000 lbs. to 18,000 lbs. if with cattle; 12,000 lbs. if with pigs; and 9,000 lbs. if with sheep. When fitted with double decks these cars will carry 18,000 lbs. loaded with pigs, and 14,000 lbs. with sheep. Such cars are also largely used for rough freight of various kinds, as coal, oil, pig-iron, lumber, staves, bark, &c.

5. The 'box' car, 30 feet long and 8 feet wide inside, is used for general merchandise, grain (mostly in bulk), flour, &c. The weight of the empty car is 20,000 lbs., and it will carry, of general merchandise, about 16,000 lbs.; of grain from 20,000 to 24,000 lbs.; and of flour 100 barrels, weighing 21,600 lbs.

The freight cars are strongly framed, and are carried on two trucks; each truck has four chilled wheels, and weighs 4,625 lbs.

A large portion of the goods traffic is carried on by the Empire Transportation Company, which owns four thousand five hundred cars, and altogether provides rolling stock and cars for 5,300 miles of railway. In the oil regions the Empire Company has also constructed 400 miles of pipes to collect the oil in large tanks. This petroleum is largely carried in bulk, in cylindrical wrought-iron tanks mounted on bogie trucks. Serious fires frequently occur from the transport of so inflammable a material.

It is a curious fact that, whilst the drivers are so well cared for, the breaks of the goods trains are usually applied from the top of the wagons, and the breaksmen ride outside and run over the top of the train when at work.

The whole of the rolling stock is provided with combined central buffers and drawbars, and the trains generally are loosely

coupled and without safety chains. On some passenger cars in the States, though not on this railroad, an improved platform and coupling, known as Miller's patent, has been introduced. The platforms are trussed to prevent vertical buckling in collisions, and the coupling, which is self-acting, holds the cars firmly together at a uniform level; thus in great measure doing away with the loose coupling, and lessening the tendency, often developed in American rolling stock, and usually caused by the breaking off of one of the platforms, to raise the end of one car and force it into the body of the next car.

Water troughs, similar to those on the London and North-Western railway, are laid down on this railroad, to supply the locomotives when running at speed. By their use express trains are enabled to run regularly, a distance of 132 miles, without stopping, in three hours and thirty-seven minutes, or at an average speed of over 36 miles an hour; and the whole distance from Pittsburgh to Philadelphia, 355 miles, in ten and a half hours, or at an average speed, including stoppages, of $33\frac{3}{4}$ miles per hour.

The heavy passenger and goods traffic is worked with great regularity. System and discipline pervade every department, and no necessary expense is spared to maintain both works and rolling stock in thorough efficiency.

Having thus described in some detail one of the best examples of railroad construction and of working in the United States, the Authors would desire to add a few facts as regards American railroads generally, to supplement the valuable information already laid before the Institution,[1] and that contained in the report of Capt. Douglas Galton to the Board of Trade.[2]

Leaving out of consideration some unimportant tramways opened between 1826 and 1831, and worked by horse power, American railroad construction fairly commenced in 1831, when a section of the Baltimore and Ohio railroad, about 60 miles in length, was first worked by steam power, the engine being of American construction. The Mohawk and Hudson railroad was opened and worked in the same year by an engine of English make of 6 tons weight, which, being too heavy, was replaced by an American locomotive of 3 tons weight.

The importance attached to railroads in the United States (a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 51; vol. xxii., pp. 305 and 540; and vol. xxviii., p. 360.

[2] *Vide* "Report on the Railways of the United States." By Captain Douglas Galton, R.E. Folio. London, 1857.

country in a great measure devoid of good roads) is plainly shown from the marvellous rapidity with which the system has been extended. Thus—

In 1830 there were		23	miles	completed and at work,	
„ 1840	„	2,818	„	„	„
„ 1850	„	9,021	„	„	„
„ 1860	„	30,635	„	„	„
„ 1870	„	52,898	„	„	„
„ 1871	„	60,568	„	„	„
„ 1872	„	66,735	„	„	„
„ 1873	„	70,651	„	„	„

representing a mile of railroad, chiefly single line, to every 583 of the population, and a total capital of £693,832,889, or £9,820 per mile; whilst in the United Kingdom—

In 1850 there were		6,890	miles	completed and at work,	
„ 1860	„	10,433	„	„	„
„ 1870	„	15,537 miles constructed, but not all open,			
„ 1871	„	15,376 miles completed and at work,			
„ 1872	„	15,814	„	„	„
„ 1873	„	16,082	„	„	„

representing a mile of railway to about every 2,000 of the population, and a total capital expenditure of £588,320,308, or £36,574 per mile.

The respective proportions of Share Capital (or Stock) and Debentures (or Bonds) are as follows:—

UNITED STATES.

Share capital, £357,067,074 = 51·5 per cent. of the whole capital.
Debentures, £336,765,815 = 48·5 „ „ „

UNITED KINGDOM.

Share capital, £449,087,573 = 73⅔ per cent. of the whole capital.
Debentures, £160,180,080 = 26⅓ „ „ „

Showing a remarkable difference in the margin of security for Debentures in the two countries.

The effect of so vast a system of railroads upon the prospects of the Union has been remarkable. During 1873 the total earnings of the railroads were £96,510,327, equal to 13½ per cent. upon their gross cost, and to £2 6*s.* 9*d.* per head of population, the working expenses averaging 65·1 per cent. of the receipts, and the net receipts 4·96 per cent. upon the total capital, including bonded debt; whilst the commerce fostered by them has reached a value estimated at least at £2,000,000,000 annually. In the early days of the railroad system the receipts from passengers were the larger item; now the receipts from goods traffic are fully 2¾ times as

great as those from passengers, the proportion being 30·8 per cent. from passengers and 69·2 per cent. from goods; a fact also observable, though in a much reduced ratio, on English railways, the proportion being 41·31 per cent. from passengers, to 55·11 per cent. from goods traffic in 1873. Railroads were indeed essential to the growth of all those portions of the Middle and Western States distant from water carriage, for without them wheat and the other farm produce forming their staples would have been excluded by the cost of transit from the Eastern and European markets. It is the opinion of practical men in the States that the limit of profitable extension westward has been reached, until the growth of population shall give rise to a larger local traffic. It is remarkable that the railroads, where parallel with the river Ohio and other navigable waters, are rapidly drawing away the traffic from them, even in heavy goods.

In this unrivalled network, whilst some of the older trunk lines are now, like the Pennsylvania railroad, thoroughly substantial, and suitable for high speeds, every gradation may be found. As a rule, the railroads, especially in the West, are opened for the least possible cost, and when the traffic increases are practically re-constructed. Many of the lines in the far West are little better than temporary roads laid upon the formation, with scarcely an attempt at ballast; and during heavy rains, or upon the melting of the snow, their condition is wretched. Yet, by the aid of the bogie truck, trains pass at fair speeds over such roads, without frequent accident. The fencing is generally very inferior, and the locomotives are, therefore, armed with a "cowcatcher," to prevent their being thrown off by stray cattle.

The gauge varies from 6 feet in the case of the "Erie," through the gradations of 5 feet 6 inches, 5 feet, 4 feet 10 inches, 4 feet 9 inches, and 4 feet 8½ inches, to 3 feet in the case of the "Denver and Rio Grande," a line of considerable length, which is only one of numerous narrow-gauge lines completed or in progress. Where the difference of gauge is small, "compromise" cars, having wheels with broad flanges, have been used with advantage; but the attempts to run the same stock from one gauge to another, where the difference is considerable, by means of adjustable wheels and other expedients, have not hitherto been successful. Such wheels work well at first, but rapidly deteriorate, and become the source of serious expense, and even danger. There has, therefore, been a desire to assimilate the gauges of lines forming through routes, and this has led to several interesting and extensive operations. Thus, the gauge of the main line of the

Ohio and Mississippi railroad, from East St. Louis to Cincinnati, was reduced from 6 feet to 4 feet 9 inches, under the direction of Mr. Thomas D. Lovett, the Chief Engineer. Preparations were made for the change by laying about one-half of the sharp curves on the outside some months in advance. The sleepers were all adzed to a gauge on each side; the inside spikes were then driven to a template. Proper sleepers were put in with new crossings, and the switch rods were cut ready for the narrow gauge, and jointed temporarily for broad-gauge use; the tools employed were of the best pattern, and made expressly for the work. The road was then divided into sections of 5 miles each, and to each section fifty men were allotted. These were subdivided, twenty-five commencing at each end of the section, and working towards each other. The men were in gangs of ten; three of them drew the spikes, three followed and threw in the rails, and the remaining four drove in the new spikes. Labourers were furnished freely by other companies for this purpose; and their distribution and feeding demanded considerable care. At midnight on a Saturday the line was cleared of broad-gauge stock, and at 4 A.M. on Sunday morning the work of narrowing was commenced, both rails being moved in, each to the extent of $7\frac{1}{2}$ inches, thus reducing the gauge to 4 feet 9 inches. By 11 A.M., or in seven hours, the narrowing was completed for the whole distance of 354 miles, and before 6 P.M. narrow-guage trains had run over the entire road. Similar operations have since been carried out with great success on the Grand Trunk and Great Western railways of Canada and elsewhere.

The mode of carrying on light earthworks, by means of large wooden scrapers, is worthy of notice. The ground is generally ploughed over first, and four scrapers, each with a pair of horses and a driver, work round and round in a circle, without stopping (one man to the gang being employed to guide the scrapers whilst filling, and to tip them when full), the circumference of the circle on the one side reaching the centre of the excavation, and on the other the spoil bank. In soft soils this is very economical. Hand and steam excavating machines are also largely used. One form is that of a plough, for excavating ditches, the earth being thrown well clear of the ditch by an endless band. Willard's machine, which is used for 'dumping' or tipping from side cutting on to embankments in the soft soils of the West, consists of a scraper, combined with an endless band, by which the earth is carried into a hopper. This being full, the whole machine is moved on to the site of the embankment, and the earth tipped. Chapman's machine is a crane, running on a temporary railway,

and having attached to it a scoop or bucket with a toothed edge of steel. This bucket is attached to a beam which rotates on an adjustable axis fixed on the jib of the crane. It can thus, by applying power to the crane, be forced into the ground and filled, then lifted to any required height, swung round, and tipped.

An examination of the official returns from the different companies, so far as they extend, shows that, whilst the weight of rails, almost universally of the Vignoles section, varies from 67 lbs. to 70 lbs. per yard on a few of the leading lines, to 30 lbs. on the narrow-guage lines, fully 60 per cent. of the length is laid with rails 56 lbs. to the yard, the weights having the next preference being 60 lbs. on the one hand, and 50 lbs. on the other.

On some lines, newly laid with steel rails with suspended joints, supports of hard wood, 9 inches wide by 2 inches thick, are inserted as longitudinal bearers under the joint, resting on the transverse sleepers on each side. Since dog-spikes only are used as fastenings, and the joints are not fished on many of the lines, there is a tendency on gradients for the rails to creep downwards, closing the joints tightly at the bottom, and leaving at the summit an open space of several inches. This space is sometimes filled with a hard wood block, driven in tightly, but in other cases with a 'plug-chair,' which is an ordinary cast-iron chair, with a tongue or dummy rail cast on the rail-seat. Plug-chairs are of various lengths to suit different-sized intervals.

The almost universal practice is to lay the permanent way on the formation. The materials, and, in the case of the Pacific and other Western lines, cars to form dwellings and canteens, are moved forward over it in a construction train. The greatest length of way thus laid in any one day on the Central Pacific railroad exceeded 10 miles; the average for a considerable period being $3\frac{1}{4}$ miles per day. Ballast is then brought over the line, and the permanent way lifted and packed, expansion plates being frequently inserted at the joints during the operation to prevent their closing up.

On the Union Pacific railroad, two sections of permanent way, 300 miles each, were allotted, the one to white men, and the other to Chinese, and the latter maintained the road better, and at 10 per cent. less cost than the former.

Where timber is abundant (especially in Canada), wooden railroads have sometimes been introduced. The permanent way, if this be not a misnomer, there costs about £240 per mile. It consists of maple rails, 4 inches wide and 7 inches deep, cut into 14-feet lengths, wedged into notches in transverse sleepers, and abutting

upon each other at the joints. Some of these rails have lasted more than five years, being run over by locomotives, having wheels with 5½ inches tread, and with no flange on the leading pair of driving wheels, at a speed of from 15 miles to 20 miles per hour. These railroads are chiefly for carrying cordwood and other lumber. Gradients of 1 in 18 are worked at a speed of 10 miles an hour by locomotives of 28 tons weight, having four coupled and four bogie wheels, the load being 80 tons, exclusive of their own weight. The adhesion is good when the rails are dry, but small when they are wet. The total cost of such a railroad, including a small amount of rolling stock, is about £1,200 per mile.

The severity of the climate in the Eastern States and Canada adds greatly to the cost of maintenance. During from four to six months, the road bed remains hard and rigid, the sleepers frozen into the ballast, and a good top is kept on the rails, as before mentioned, only by 'shimming,' or packing with hard wood wedges between the rail and the sleeper. Moderate falls of snow are cleared by a small plough attached to the cowcatcher; but for heavy drifts snow-ploughs of more elaborate construction are necessary; and, even with these, days are often consumed before the line can be cleared. Trains have, in some instances, been so long blocked in this manner as to render the feeding of the passengers a matter of serious difficulty. The plough (Plate 7) is that now used on the Grand Trunk railway. It is mounted on two bogie trucks, and is 30 feet long, 7 feet 7 inches high to the top of the plough and 11 feet high in the hinder part. It is fitted with expanding wings for throwing out the snow, and with a movable apron for clearing the rails and the space between them. There are also scrapers to clear the rails of ice. The interior is provided with seats and a stove. The plough is propelled by one or more locomotives, as may be required, as many as five being sometimes necessary. When the frost breaks up in the spring, the state of the road for some weeks is such as to demand the most vigilant care, and a large expenditure to restore it to proper line and level.

The water tanks are of special construction, and are generally covered with wood. In the best forms, air-spaces and layers of sawdust are interposed to keep out the frost; and the pipes are arranged to empty themselves of water. The tanks are often supplied by pumps worked by windmills.

Progress in railroad construction in the United States has not extended hitherto, in any great measure, to lines for the daily use of those who dwell in the chief cities. Frequently the railroads have their termini at a long distance from the business centres; and in

New York especially, great inconvenience arises from this cause, the requirements of the traffic being most inadequately met by the horse-railroads. These are laid with rails projecting above the surface of the street, and are a source of danger to ordinary vehicles, and in the narrow and crooked thoroughfares of the older part of that city bring about serious blocks of the street traffic. Goods, and a few passenger trains are still conveyed through the streets by horses into stations at right angles to the thoroughfare, the cars, fitted with the bogie, readily turning into them round curves of small radii. Whilst this is true of the large centres of trade, it is curious, on the other hand, to notice how main lines are carried on the level, and without protection, across the streets of considerable towns, the express trains often running through without stopping.

A commencement has now been made in New York to remedy the evils above referred to, by the construction of a large terminal station at 42nd Street, and of an underground railroad northwards to the New York Central and Haarlem railroads, the works of which are difficult and costly. This line, however, when completed, will only bring the traffic to a point still 4 miles distant from the business centre.

The railroad system having extended so largely on both sides of the great rivers of the West and North-West, colossal works have been carried out at St. Louis, at Buffalo, and elsewhere, to establish through communications. Some of these works, involving very difficult foundations, possess the greatest practical interest; and detailed descriptions of them by the Engineers engaged would prove most valuable additions to the records of the Institution.

In conclusion, the Authors desire very heartily to acknowledge the courtesy with which Mr. A. J. Cassatt, the General Manager, Mr. Isaac Dripps, Superintendent of Motive Power, Mr. Collins, Mechanical Engineer, and other officers of the Pennsylvania railroad have specially prepared the detailed information necessary for this communication. They are also indebted to Mr. Eaton, of the Grand Trunk railway, whilst they have made much use of the statistics published by Mr. Henry V. Poor, in his Manual of the Railroads of the United States, and by the Committee of Stockholders of the Pennsylvania Railroad Company.

The communication is accompanied by a series of drawings, from which Plates 4, 5, 6, and 7 have been compiled.

APPENDIX.

Table I.—Statistical Returns as to Pennsylvania Railroad.

Fiscal Year.	Train Mileage.	Passengers carried.	Tonnage moved.	Gross Earnings.	Working Expenses.	Net Revenue.	Dividends.		Percentage of Working Expenses to Gross Receipts.	Approximate Sterling Value of the Currency Dollar.
							Amount.	P. c.		
				$	$	$	$			s. d.
1861	4,266,831	1,070,955	1,620,586	7,300,001	3,653,063	3,646,938	795,846	6	50	..
1862	4,899,426	1,143,418	2,223,051	10,304,290	5,431,072	4,873,218	986,842	8	53	..
1863	5,327,884	1,707,386	2,265,413	11,891,413	6,780,000	5,111,413	1,206,060	9	57	2 8½
1864	5,753,906	2,587,514	2,764,876	14,759,058	10,693,944	4,065,114	1,523,637	10	72	1 9½
1865	6,338,032	2,861,836	2,798,810	17,459,169	13,270,058	4,189,111	1,997,265	10	76	2 9
1866	7,080,026	2,673,568	3,452,718	16,583,883	12,790,909	3,792,974	1,737,969	9	77	2 10½
1867	7,740,290	3,347,486	4,000,538	16,340,156	12,080,300	4,256,856	1,337,669	6	74	2 11½
1868	8,407,490	3,747,178	4,722,015	17,233,497	11,860,984	5,372,513	3,242,282	8	69	3 0
1869	9,207,848	4,229,363	5,402,991	17,250,812	12,203,268	5,047,544	3,075,643	10	71	3 4
1870	10,185,233	4,352,769	5,427,401	17,531,707	11,260,085	6,271,622	3,455,357	10	64	3 7½
1871	11,904,317	4,699,985	6,575,843	18,719,837	11,823,433	6,896,404	3,625,062	10	63	3 8½
1872	13,380,957	5,250,393	7,844,778	22,012,525	13,764,673	8,247,852	4,711,497	10	63	3 7½
1873	16,111,315	5,879,684	9,211,231	24,886,006	15,440,305	9,445,701	5,918,140	10	62	3 8

TABLE II.—PERFORMANCES of LOCOMOTIVES on the PENNSYLVANIA RAILROAD.

Year.	No. of Freight Engines.	No. of Distributing Engines.	No. of Shifting Engines.	Average Tons moved 1 mile by each Engine, including Distributing and Shifting Engines.	Average Mileage of each Freight Engine, including Distributing Freight Engines and Shifting Engines.	Rate per Ton per Mile paid for moving Freight.
						Cents.
1864	235	18	13	1,581,305	17,448	1·87
1865	232	24	21	1,516,463	17,987	2·28
1866	253	25	27	1,682,302	18,288	1·82
1867	270	22	36	1,724,566	18,611	1·54
1868	278	29	38	1,958,770	19,521	1·25
1869	314	25	52	1,925,093	18,342	1·20
1870	316	26	53	2,091,088	19,526	1·00
1871	338	30	58	2,375,334	21,839	0·87
1872	401	34	63	2,389,847	22,302	0·886
1873	456	34	77	2,442,384	23,213	0·857

TABLE III.—LOCOMOTIVES and ROLLING STOCK of the PENNSYLVANIA RAILROAD.

Description.		1861.	1862.	1863.	1864.	1865.	1866.	1867.
No. of Locomotives.		229	255	290	314	368	362	428
Cars	Passenger, &c.	157	158	173	232	230	264	302
	Freight and Coal	3,086	4,016	4,926	4,845	4,842	4,878	5,221
	Service	558	562	616	709	750	728	727
Totals		3,801	4,736	5,715	5,786	5,822	5,870	6,250[1]

Description.		1868.	1869.	1870.	1871.	1872.	1873.
No. of Locomotives.		434	477	482	514	593	668
Cars	Passenger, &c.	318	346	331	403	718	763
	Freight and Coal	5,490	5,643	6,632	6,685	11,211	13,029
	Service	718	738	731	1,440	2,168	2,592
Totals		6,526	6,727	7,694	8,528	14,097	16,384[2]

[1] In this year 2,536 coal cars on the road were owned by other parties than the company.

[2] In this year 8,501 freight and coal cars on the road were owned by other parties than the company.

TABLE IV.—COMPARATIVE STATEMENT of LOCOMOTIVES and ROLLING STOCK in the UNITED KINGDOM, in INDIA, and in the UNITED STATES.

Description of Vehicles	United Kingdom. 16,082 Miles open.		India. 5,674 Miles open.		United States. 70,651 Miles open.	
	Total No.	No. per 10 Miles.	Total No.	No. per 10 Miles.	Total No.	No. per 10 Miles.
Locomotives . .	11,435	7·1	1,343	2·36	13,746	2 nearly.
Passenger Cars .	36,762	21·0	3,729	6·57	25,854[1]	3·6
Goods Wagons .	329,023	205·0	23,432	41·3	678,144[1]	95·0

[1] In order to institute a fair comparison, the American passenger cars and goods wagons, having double the capacity of those of the United Kingdom and India, are each counted as two.

TABLE V.—The following is a list of all the CURVES on the PENNSYLVANIA RAILROAD MAIN LINE (except the PHILA. DIV.) whose radius is less than 1,000 feet, giving the position and length of same.

Stations.	Radius.	Length of Curve.	Stations.	Radius.	Length of Curve.
	Miles.	Feet.		Miles.	Feet.
Rockville	819·0	907	West of Alligrippu's .	..	278
West end Susq. Bridge.	996·0	1041	,, ,, ,, .	955·4	744
East of Duncannon. .	716·8	680	Bennington . . .	716·8	1130
Mexico	955·4	958	Gallitzin	955·4	884
Barnifflin and Lewistown, 136 m. post .	955·4	725	West of Lillies . . .	..	1360
			,, ,, ,, . . .	882·0	1380
Bixless Water Station .	955·4	776	,, ,, ,, . . .	955·4	258
East of Lewistown . .	955·4	1124	,, ,, ,, . . .	..	1926
West of Mapletown. .	881·9	336	,, ,, ,, . . .	..	1410
East of Huntingdon .	955·4	575	Big Viaduct . . .	790·8	1028
Petersburg	955·4	888	West of Big Viaduct .	974·3	514
,, west of .	955·4	547	East of Conemaugh .	955·4	1278
East of Spruce Creek .	996·9	759	,, ,, ,, .	..	856
,, ,, Union Furnace	955·4	1649	Johnstown, C. I. Works	..	551
West ,, ,, ,,	955·4	961	Dormock Point . .	739·9	1521
East of Birmingham .	955·4	432	West of Dormock Point	955·4	1502
,, ,, ,, .	954·4	1079	Lockport	..	1443
,, ,, ,, .	955·4	416	West of Bolivar . .	..	1494
West ,, ,, .	955·4	908	East of Blairsville Int.	819·0	663
,, ,, ,, .	955·4	875	,, ,, ,, .	954·4	416
Tyrone	955·4	796	West of Greensburg .	716·8	1222
West of Altoona . .	955·4	381	Turtle Creek . . .	819·0	1581
,, ,, ,, . .	..	682	East of Brinton's . .	955·4	391
East of Kittanning Point	819·0	1231	,, ,, ,, . .	..	600
At ,, ,,	674·7	804	At Brinton's . . .	..	900
,, ,, ,,	637·3	1464	West of Brinton's . .	..	683
West of ,, ,,	955·4	308	,, ,, ,, . .	929·6	500
,, ,, ,, ,,	..	1380	West of Braddock's Field	955·4	716
,, ,, ,, ,,	716·8	938	,, ,, Millvale . .	..	800
Alligrippu's . . .	..	628			

TABLE VI.—POSITION of POINTS on the PENNSYLVANIA RAILROAD at which the AVERAGE GRADE CHANGES, and the ELEVATION of these POINTS.

Stations.	Distance from Philadelphia.	Elevation above High Tide.	Stations.	Distance from Philadelphia.	Elevation above High Tide.
	Miles.	Feet.		Miles.	Feet.
West Phila.	0·0	20·0	McVeytown . . .	178·4	515·3
Athensville	7·7	351·0	Manayunk	183·0	511·6
Beyond Villa Nova .	11·7	424·0	Newton Hamilton . .	188·5	592·0
„ Radnor . . .	13·8	390·0	Mount Union . . .	191·4	590·5
„ Reeseville . .	18·2	518·0	Mapleton	194·5	586·3
„ Paoli . . .	20·3	544·0	Mill Creek	197·8	596·5
„ Malvern . .	21·8	540·0	Huntingdon . . .	203·1	615·4
East of Downingtown .	32·1	247·0	Warrior Bridge Water Station	207·7	674·3
Beyond Columbia . .	37·2	372·0	Petersburg	209·6	670·9
„ Coatesville . .	38·8	372·0	Barree	212·9	716·6
„ Parkesburg .	44·9	554·0	Spruce Creek . . .	215·5	769·8
„ Renningtonville	47·6	480·0	Birmingham . . .	220·3	859·5
East of Gap	50·9	566·0	Tyrone	222·9	901·4
West of Leaman Place.	57·8	358·0	Bells Mills	230·3	1053·3
East of Bird-in-hand .	60·0	392·0	Altoona	237·2	1171·3
West „ „ .	62·2	340·0	West of Altoona . .	238·2	1223·5
„ „ „ .	63·55	377·0	„ „ „ . .	238·4	1220·5
Big Conestoga Bridge .	67·1	300·0	Kittanning Point . .	242·4	1581·5
West of Lancaster . .	69·6	364·0	East of Allegheny Tunnel	248·2	2116·8
Little Conestoga Bridge[1]	72·3	307·0	Gallitzin	249·0	2154·4
Landisville	75·9	398·0	Name not known . .	252·1	2011·2
Big Chiquis Bridge .	78·1	354·0	West of Wilmore . .	262·6	1542·1
„ „ „ .	78·9	370·0	East of Summer Hill .	264·0	1562·2
Little Chiquis Bridge .	80·1	304·0	West of Conemaugh .	275·0	1176·4
„ „ „ .	81·0	368·0	Johnstown	275·9	1176·4
East of Elizabethtown .	85·9	468·0	East of Ninevah . .	285·0	1119·0
West „ „ .	88·8	492·0	„ „ New Florence	289·2	1074·7
Int. with Col. Br. E. of Middletown . . .	95·6	306·0	West Houston's . .	291·8	1040·4
Harrisburg[1]	105·4	313·0	Names not given . .	295·6	1023·9
Dillerville Int. of Col. Br. with new Line[2] .	70·0	351·0	„ „ „ . .	303·2	1136·4
West of Dillerville[2]. .	71·2	317·0	„ „ „ . .	308·5	1199·2
„ „ Rohrerstown[2] .	74·6	416·0	East of Latrobe . .	312·1	999·4
East of Mountville[2]. .	75·6	416·0	„ „ „ . .	313·4	997·3
Columbia[2]	80·9	242·0	Carré Tunnel . . .	318·3	1201·8
Int. with Union Line[2] .	99·5	306·0	East of George's . .	319·0	1170·1
West of Harrisburg . .	107·4	339·6	West of „ . .	319·6	1191·7
„ „ „ . .	109·8	327·2	East of Greensburg .	322·3	1058·3
East end Susq. Bridge .	111·0	343·4	West of „ . .	324·4	1163·6
Aqueduct	123·3	370·3	East of Penn. . . .	328·5	963·7
Baily's	128·5	379·9	West „ „ . . .	329·1	976·2
Newport	133·2	387·5	Walls	339·2	744·4
Millerstown	138·3	401·4	East of . . .	342·0	742·2
Thompsontown . . .	143·4	412·0	Swissvale	345·8	915·5
Tuscarora	148·6	421·6	East Liberty . . .	349·4	910·7
Perryville	152·0	434·8	East of Pittsburg . .	350·8	744·5
Mifflin	154·7	434·3	Pittsburg Yard . .	353·5	752·3
Lewistown	166·4	490·8	„ Union Depôt	353·9	737·9
Granville	170·3	491·2	„ Dequesne Depôt .	354·8	720·9

[1] Mt. Joy Route.

[2] Columbia Route 3·9 miles longer than Mt. Joy Route.

TABLE VII.—LIST of BRIDGES over STREAMS, on MAIN LINE PENNSYLVANIA RAILROAD.

No.	Names.	No. of spans.	Clear span.	Length of truss each span.	Total length of Bridge.	Height of truss.	Width, extreme, lower chord.	Angle of skew.	Remarks.
			ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	° ′	
15	Valley Creek . . .	6	64 11	73 0	438 0	8 0	20 0	..	Deck, iron truss.
17	East Brandywine . .	3	78 0	85 6½ 85 4 85 6½	256 5	9 0	20 0	..	Ditto.
18	West Brandywine . .	6	125 5 125 6 125 0 125 8 125 10 125 6	139 0	834 0	15 9	22 0	..	Ditto.
21	Octorora Creek . . .	1	40 7	45 0	45 0	4 8	19 6	43 40	Deck, iron plate.
28	Pequea „ . . .	1	125 5	132 8	132 8	19 0	28 5	..	Through, iron truss.
29	Mill „ . . .	3	77 7	85 9½ 85 7 85 9½	257 2	9 0	20 0	..	Deck, iron truss.
31	Big Conestoga Creek .	3	121 0 125 0 45 5	130 0 130 0 53 0	313 0	13 6	22 3	..	Ditto.
33	Little „ „ .	2	58 6	66 0	132 0	6 6	19 6	..	Deck, iron plate.
38	Strickler's	1	58 6	66 0	66 0	6 6	19 0	42 30	Ditto.
40	Chiques	3	35 0	40 0	120 0	4 6	19 6	..	Ditto.
54	Conewago	3	35 0	40 0	120 0	4 6	19 6	..	Ditto.
85	Swatara	4	67 6 69 3 69 3 67 9	75 5½ 75 3 75 3 75 5½	301 5	8 7	19 10	..	Deck, iron truss.

TABLE VII.—*continued.*

No.	Names.	No. of spans.	Clear span.	Length of truss each span.	Total length of Bridge.	Height of truss.	Width, extreme, lower chord.	Angle of skew.	Remarks.
			ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	° ′	
86	Union Canal . . .	1	113 6	119 6	119 6	23 0	30 4	..	Through, iron truss.
88	Pennsylvania Canal . .	1	72 0	80 0	80 0	7 9	29 0	..	Ditto.
98	Lower Canal, Rockville .	1	106 6	114 0	114 0	19 1¼	29 0	36 0	Ditto.
100	Upper „ „ .	2	55 3	62 10	125 8	5 1	18 6	48 45	Deck, iron plate.
101	Susquehanna	23	154 0	160 0	368 0	18 0	18 9	..	Deck, wooden Howe truss with arches, single track.
103	Sherman's Creek . . .	4	71 4½ 70 9 71 3 71 1½	77 3	309 0	7 5	18 0	..	Deck, iron truss.
105	Juniata „ . . .	3	36 0	40 0	120 0	2 8¾	19 2	..	Deck, iron plate.
112	Raccoon „ . . .	1	48 0	53 1	53 1	4 8	19 6	..	Ditto.
114	Perryville	2	99 8	106 9½	213 7	15 4	20 3¼	..	Deck, iron truss.
115	Granville	5	120 9 to 121 6	126 4	632 7	15 6	22 3	..	Ditto.
116	Ditto Canal	1	53 10⅞	58 8	58 8	4 8	19 6	81 0	Deck, iron plate.
117	May's „	1	60 8	73 1	73 1	6 0	20 11½	62 15	Ditto.
118	Ditto River	5	119 0 to 120 6	127 7⅛	638 5⅝	13 6	22 3	..	Deck, iron truss.
122	Manayunk	5	121 0	125 4	626 8	13 6	22 0	..	Ditto.
123	Ditto Canal	1	65 0	73 1	73 1	8 0	20 0	62 15	Ditto.
124	Mt. Union Canal . .	1	121 6	130 0	130 0	15 6	22 3	..	Ditto.
125	Ditto River	4	121 6	128 0	512 0	15 6	22 3	..	Ditto.
126	Vandervander . . .	5	96 0	102 2	511 0	10 0	23 6	..	Ditto.
127	Bridgeport	1	106 6	114 0	114 0	19 1¼	29 0	36 0	Through, iron truss.
131	Huntingdon	1	51 0	57 2	57 2	4 8	19 6	31 15	Deck, iron plate.
133	Shaver's Creek . . .	2	70 2 70 6	77 6	155 0	8 0	19 3	..	Deck, iron truss.

131	Neff's	2	49 3 48 0	55 11	111 10	1 8	19 6	51 0		Deck, iron plate.
136	Shuman's	3	93 6 92 10 93 7	102 7 102 2 102 7	307 4	10 0	23 6	45 30		Deck, iron truss.
138	L. Juniata No. 1	1 3	38 0 72 9 75 0 72 9	44 11 85 9½ 85 7 85 9½	44 11 257 2	4 5 9 0	19 4 20 0	30 50 30 50		Deck, iron plate. Deck, iron truss.
139	Ditto No. 2	2	79 7 79 1	85 9½	171 7	9 0	20 0	61 15		Ditto.
140	Ditto No. 3	3	72 10 75 0 72 4	85 9½ 85 7 85 9½	257 2	9 0	20 0	45 45		Ditto.
141	Ditto No. 4	5	46 0 44 7 47 0 47 0 48 0	52 4 51 0 52 7 53 4 55 3	289 0	4 8	20 0	..		Deck, iron plate.
142	Ditto No. 5	2	83 0	86 9	173 6	20 8	33 4	..		Deck, iron truss.
143	Ditto No. 6	3	74 10 75 2 76 3	86 0	258 0	9 0	20 0	43 0 43 0 45 0		Ditto.
144	Ditto No. 7	2	90 0	97 6	195 0	10 0	18 0	35 0		
146	Ditto No. 8	2	86 6½	95 9½	191 7	11 0	20 0¾	39 26		Ditto.
147	Ditto No. 9	3	75 0	85 9½ 85 7 85 9½	257 2	9 0	20 0	40 15		Ditto.
148	Ditto No. 10	2	94 9 97 0	100 0	200 0	12 0	20 0	45 0		Ditto.
149	Ditto No. 11	3	59 6	66 0	195 5	7 3	20 0	..		Ditto.
150	Ditto No. 12	3	49 5	58 0	174 0	5 2	19 6	..		Deck, iron plate.
152	Ditto No. 13	4	43 9	48 9	195 0	4 8	19 6	..		Ditto.
166	At Summer Hill	3	75 0	81 0	243 0	9 0	20 0	..		Deck, iron truss.
170	At South Fork	3	50 0	55 4	166 0	5 2	20 0	..		Deck, iron plate.
172	Two miles E. of Conemaugh	2	65 0	69 8	138 6	6 6	20 0	..		Ditto.
176	Over Conemaugh R.	5	71 0	76 0	380 0	8 0	20 0	..		Deck, iron truss.

TABLE VIII.—DIMENSIONS OF LOCOMOTIVES, PENNSYLVANIA RAILROAD.

	Class.						
	A.	B.	C.	D.	E.	F.	G.
Area of grate	ins. ins. 35 × 66⅞	ins. ins. 35 × 72¾	ins. ins. 35 × 72½	ins. ins. 35 × 60	ins. ins. 35 × 67¼	ins. ins. 35 × 44¼	ins. ins. 35 × 55
Number of flues	143	155	151	119	123	89	130
Length of flues	ft. in. 11 0½	ft. ins. 10 8	ft. in. 11 0¾	ft. ins. 12 9½	ft. ins. 12 3¾	ft. ins. 12 6	ft. ins. 9 8
Outside diameter of flues	ins. 2¼	ins. 2¼	ins. 2¼	ins. 2½	ins. 2½	ins. 2¼	ins. 2
Number of driving wheels	4	4	4	6	6	6	4
Diameter of driving wheels	ins. 67	ins. 61	ins. 61	ins. 55	ins. 55	ins. 44	ins. 55
Length of rigid wheel base	96	102	102	149	152	137	84
Diameter of cylinders	17	18	17	18	18	15	15
Length of stroke of cylinders	24	24	24	22	22	18	22
Weight in working order:—							
„ on forward drivers	lbs. 23,400	lbs. 24,800	lbs. 23,200	lbs. 18,000	lbs. 19,200	lbs. 19,350	lbs. 19,400
„ „ main „	..	..	..	18,300	19,400	22,450	19,800
„ „ back „	22,000	22,900	22,600	18,200	18,000	21,700	..
„ „ truck	26,500	25,400	25,500	20,800	19,000	..	20,800
Total weight	71,900	73,100	71,300	75,300	75,600	63,500	60,000

Mr. Charles Douglas Fox remarked, that this Paper had grown out of visits which his brother and he had made to the Pennsylvania railroad, and of the kind offer by the officers of the company to supply the detailed information necessary for such a communication. He knew, of course, of the excellent Papers by the late Mr. Colburn,[1] and of the long discussions to which they gave rise, so that he had some hesitation in presenting a further one dealing apparently with the same subject. But he felt that, although the whole question of locomotives and of rolling stock in the United States had been brought forward, no complete and systematic account of any particular railroad had been placed before the Institution, and he had therefore chosen for description one of the best railroads in that country, both as regarded construction and working.

The progress of American railroads during the last few years had been very great. In five years there had been constructed no less than 28,396 miles, involving an expenditure at the rate of about £55,000,000 per annum. This rate of increase, however, was abnormal, and was chiefly brought about by the large land grants made by the legislatures to the companies. The result had been to cause extensions into districts where probably railways might not otherwise have penetrated. The chief extension of late years had been towards the west; and it was considered by some of the most eminent authorities that it had now more than reached (at any rate for some years) its extreme profitable limit. Many of the western railways did not pay. They depended for their traffic chiefly upon agricultural produce, and the great market for that produce was in Europe; so that the farmer had to sell his corn at Liverpool prices, less the cost of land transport to the eastern seaboard and the freight to Liverpool. There was, therefore, a limit to the distance westward at which corn could be profitably grown for the European market. In the report of the Investigating Committee already referred to, it was stated that the western extension of railroads for agricultural purposes had reached its limits, as regarded dealing with the European supply; and that what was now needed in the west was the growth of manufactures, in order that manufacturers and agriculturists might provide traffic for each other. The gross earnings of the American railroads in 1873 amounted to about 13 per cent. of their cost; the net earnings during the same period were 4·96 per cent., and the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 540, and vol. xxviii., p. 360.

earnings per head, £2 6*s.* 9*d.* If, therefore, the future extension was not carried on in too rapid a manner—if the railroad system had rest, it was clear that, with an immigration of over one million persons annually, the net receipts must largely increase, and the general financial results become satisfactory. The Pennsylvania Railroad Company had been, on the whole, the most successful in the country. This was attributed to three causes. (1) Its originators had the wisdom to purchase large quantities of land at the chief stations. Many people then thought them wasteful and extravagant, but their foresight had been of the utmost importance to the company as regarded its great centres of trade, especially at Philadelphia. (2) The main line was now worth more than double the original cost. (3) The company had the control, in one way or another, of 5,933 miles of railroad, by means of working agreements, or by holding large quantities of stock, giving them the chief voice in the management. With regard to the large goods wagons employed in America, some of them 28 or 30 feet long, they might be valuable for through freight for long distances, but he thought they must be inconvenient where the goods had to be picked up at roadside stations. This great length had probably grown out of the use of the bogie truck. As to the question of chilled wheels, he had heard no difference of opinion either in America or in Canada. He was present when attempts were made to break up some of the wheels, and he was greatly surprised at their tenacity. It seemed more like trying to break wrought iron than cast iron. For wheels which, as in the case of leading trucks, had to perform the duty of guiding the train, and which had their tires constantly pressing against the rails, there was nothing, in the opinion of American managers, like cast iron. The large and cumbrous snow-plough (Plate 7) was not too strong for its purpose. The stove was an important part of the arrangement. It was not an uncommon thing (it had happened to a relative of his own) to spend three days and three nights in one of the ploughs. Mr. Carl Pihl, of Norway, had been successful in stopping snow-drifts, by fencing placed at a short distance from the line. He explained the traffic diagram used in working single lines in America, which was similar to that introduced long since by Mr. Brunlees, and to the one exhibited by Mr. Price Williams in the discussion on railway signals.[1] It was arranged with pins and threads; and as the train despatcher, who had charge of 100 or 150 miles of line, was

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 233.

informed by telegraph of any hitches, he could show by moving the pins how the stoppages and crossings of the trains were to be modified.

Mr. F. W. Webb would have been glad if a description had been given of the arrangements for working the traffic, especially with regard to refuge sidings, which, instead of being on one side of the line, were generally put in the middle, between the up and the down lines, so that they could be used for traffic running in either direction. Where the bulk of the traffic went sometimes in one direction and sometimes in another, that plan was useful, and it might, he thought, be copied with advantage. He had spent a good deal of time on the Pennsylvania railroad, and he agreed with the Authors, that the examples there presented of locomotive practice were about the best that could be seen in America. Cast iron was used to a larger extent than in this country, and he thought, in some cases, with advantage. The locomotives also had much smaller driving wheels. In this country the limits of driving wheels for a properly-balanced engine had been exceeded. Since his visit to America he had investigated the matter, and was now running some of the fastest express trains on the London and North-Western railway, including "The Flying Scotchman," with locomotives having driving wheels of 66 inches in diameter. The first engine of that class had run 26,000 miles without needing repairs, and would probably run 26,000 miles more before showing any sign of wearing out. It seemed likely that the carriage of petroleum on the railroad in question would be superseded, as pipes were being laid down, and it was proposed to pump it to towns 20 or 30 miles distant. He believed that Mr. Pullman had done great service to the travelling public in America; but the Pullman car was an unwieldy thing to deal with; and he thought after it had been used for a short time in England passengers would be content with a smaller carriage. For himself he should be sorry to ride in a carriage the only exit from which was at the ends, where the adjacent carriages were trying to get in, or, in familiar phrase, to telescope it, as occasional collisions could not be avoided; and he should like to have something better than an arm-chair to prevent his being shot a distance of 40 feet into a plate-glass window. Another disadvantage was that the passenger had not the control of the window, as in ordinary carriages. There was also the objection of dead weight. The cars brought over to this country he understood weighed 21 tons, to carry twenty-four passengers; but on going to bed the passengers went into another car, leaving the

other empty. This was not the way to reduce the weight of the trains, which was felt to be so desirable. When Sir Joseph Whitworth took the matter in hand, some time ago, he had hoped that something might be accomplished, but no result appeared hitherto to have been arrived at. The high-class steel, referred to in the Paper, was said to have a tensile strength of 90,000 lbs.; but he was satisfied when steel had a breaking strain of 65,000 lbs. per square inch. This would stretch 30 per cent. before breaking; and he found no difficulty, in the boilers he had made, in keeping to a uniform standard—within 5,000 lbs. per square inch. He had only a short experience of the Westinghouse break. The vacuum break had been in use on the St. John's Wood line, and was being tried on the South Junction at Manchester. There were no chilled tires on the North-Western line. He thought a great deal of the difficulty in connection with the use of steel tires in America would be overcome if the outer rail were elevated on curves instead of reliance being placed on the bogie truck for the guiding. It was stated that an engine took 223 tons up the incline at Altoona in thirty-five minutes. It was also stated that another engine took 215 tons up the same incline, and had evaporated 2,400 gallons of water in less than an hour. He thought there must be some inaccuracy in the statement with regard to the evaporative power of the engine, or that water as well as steam passed into the cylinder. It was not possible for an engine to evaporate so large an amount of water in the time.

Mr. T. W. Worsdell believed he inaugurated the experiments on the Pennsylvania railroad to which reference had been made. He thought there must be a mistake in some of the figures cited. The amount of water evaporated in going up the gradient of 1 in 55 from Altoona to the summit of the mountain had, to his knowledge, never exceeded 1,600 gallons, and that great evaporation was sometimes due to saturated steam. The greatest load he remembered an engine taking up the mountain was about 240 tons, and that was accomplished just within the hour, the evaporation of water being 1,600 gallons. During his connection with the Pennsylvania railroad the company began the manufacture of steel boilers, and entered into it more extensively than any other railway or manufacturing firm. He had been engaged in the construction of about one hundred and twenty steel boilers and two hundred and fifty fire-boxes. When the copper fire-boxes were worn out very thin crucible steel was substituted. It was stated in the Paper that all the steel was subjected to a particular test, and the tensile strength was given as 90,000 lbs. per square inch, but the

steel in question could not be submitted to that test. Some of it had a tensile strength of 90,000 lbs., but that was used for the barrel plates of the boiler. The fire-box was steel of a lower temper, and was tested by heating it to red heat and plunging it in cold water. The steel was supposed to be perfect after the first dipping; but it was ascertained by experience that if heated and dipped seven times, it became slightly softer; after that it began to lose its softness. The thickness of the plates was $\frac{1}{4}$ inch; he would willingly have used plates of $\frac{3}{16}$-inch, if it had been possible to screw the stays in. After dipping, a mechanical test showed that the steel was sufficiently soft and pliable for flanging purposes. In the construction of steel fire-boxes, it was discovered that if the flanges were not turned away from the fire in the front part of the box the rivet-holes were apt to crack, even with the best steel. On coming to this country, in 1870, he found that Mr. Webb had a fire-box constructed in the same way of steel plates, and with flanges turned away from the fire; and, curiously enough, with a very thin copper lining such as was used for caulking. On the Pennsylvania railroad it was customary to stay the roof of the fire-box according to the old-fashioned plan, bracing it from the crown bars to the roof of the boiler. But when steel fire-boxes were employed it was ascertained that, with vertical steel sides, the pressure could be supported without staying. The practice of staying to the roof of the boiler was then discontinued, without even a partial explosion, or a fracture ensuing. It appeared singular, however, to trust entirely to the flat top of the fire-box, supported only by bar stays, and a boiler was accordingly ordered by the superintendent to be stayed in the usual way; and yet that part of the boiler blew up after it had been about three years in service. That was the result of over-pressure; but the others had, no doubt, been subject to the same pressure many times. The side of the exploded boiler had a seam, and there appeared to be some expansion and contraction working against it, which caused the guttering in so short a time, and led to the explosion. The other boilers were examined immediately to ascertain whether they were defective, but there was not the slightest sign of guttering. Another feature, peculiar to American locomotives, was the great use of cast iron, which was employed even for slide valves. He knew from experience that cast-iron valves lasted longer than the brass valves in common use in England, especially those with white metal let into them. A valve was seldom broken, although the area was large. The weak point, if any, about the ordinary American cylinder was

the enormous steam chest. The driving wheels were commonly solid. The Pennsylvania Company was, he believed, the first to make them with hollow spokes and rims, which they did with great advantage. He had seen many outside cylinder coupled express engines with every spoke broken, the crank rattling within the spokes, and the wheel only held together by a good English steel tire; but he had never known one of the hollow-spoke wheels to be broken except in cases of collision or "jumping the track." He remembered a curious circumstance in connection with hollow-spoke wheels. Water had been applied to cool the tire on, without regard to stopping the core-holes; and in the winter the spokes were found cracked in a longitudinal direction. It seemed that the water had got into the holes and cracked the spokes. This, of course, was an unforeseen accident. The spokes answered very well, and were extremely light. The practice of balancing with lead was a bad one. The method employed was that of casting a cavity in the wheel and pouring the lead in. By constant use the lead became pounded into a smaller size. This system was a source of great trouble, and he could not recommend it. The smoke-burning arrangements were similar to those adopted in this country, and of great variety; but the most efficient, and one which he believed was not adopted in this country, was an arch stretching from the tube plate below the tubes up towards the fire-door. The arch was made with flat bricks, which extended across the fire-box, supported by the water tubes, these tubes forming a kind of loop on which the bricks were laid. One advantage of this arrangement was ascertained accidentally. An engine had got short of water,—the pumps would not work, or the injectors had failed,—but there was a kind of injection of water on the top of the fire-box which kept it cool until the fire was put out. It was the practice to carry heavy fires, and to employ large fire-boxes, so that these water tubes formed a useful safeguard. The tubes of the boiler were large, a curious circumstance seeing that there was a sharp exhaust. The exhaust was necessarily sharp, on account of "the smoke stack," or funnel, being composed of a quantity of obstructive material, such as the inverted cone, the netting, and sometimes double pipes, causing the draught to travel up and down two or three times. He was inclined to think there was too much complication in these arrangements. In some of the illustrations exhibited by the Authors, the engines had not the American type of chimney. The netting was adopted in consequence of the old system of wood-burning. In dry seasons, the sparks, if they escaped, set fire to the long grass by the side of the road, and the

flames spread to the neighbouring property. The public appeared quite aware of any change in the formation of this part of an engine; for if an engine passed, exhibiting any difference in construction, and a fire happened in the neighbourhood of the railroad, it was always attributed to the emission of sparks. It might be, in such cases, that the apparatus for preventing the emission of sparks was more perfect inside the boiler or smoke-box than was apparent outside. The tubes for goods engines were generally $2\frac{1}{2}$ inches in diameter, and for passenger engines about $2\frac{1}{4}$ inches. The longest distance he knew of from tube plate to tube plate was 14 feet 10 inches.

Mr. Bramwell asked if Mr. Worsdell could state the percentage of carbon in the two kinds of steel, used in the barrel and in the fire-box respectively.

Mr. Worsdell said that the steel was only tested mechanically, not chemically, but he should imagine that the percentage of carbon in the fire-box steel would be 0·18 or 0·20, and in the barrel steel 0·24 or 0·25.

Mr. Barlow said that when engineers travelled abroad and brought home the results of their experience, the information thus obtained was most valuable. It was important, however, that the facts should be given accurately; or, at any rate, that the meaning of the Authors should be properly understood. He was not quite sure whether the remarks in the Paper as to steel had been quite understood. It had been stated that steel of the tensile strength of 90,000 lbs. to the square inch could not bear the test of being chilled and bent double. But it was said in the Paper that "a sample of every plate of steel used in the construction of a boiler is tested by being heated to redness, and then plunged into cold water; after which the same piece, while cold, is bent double." And again, "The tensile strength of some of the steel, which is made at Pittsburgh, is 90,000 lbs."

Mr. Fox said he did not intend to speak of the two steels as identical.

Mr. Barlow thought that the statement with regard to the use of cast-iron chilled wheels, as compared with steel, was not quite clear. It was alleged that steel wheels would not bear the severe shock of guiding a locomotive over the sinuosities of the line, while chilled wheels answered the purpose perfectly, very rarely breaking, and one such wheel would outlive at least three steel wheels. Farther on it was stated, that the driving wheels of engines, although made of cast iron were tired with steel. It was difficult to understand how one material was

required for a carriage wheel and another material for a driving wheel. Some explanation on that point was required. He also desired to ask whether the time said to have been occupied in relaying so extensive a length of line—he believed over 300 miles—namely, seven hours, was based upon official information, or was merely a hearsay statement from the engineers of the line. If it was a fact, it was one of the most remarkable performances on record. Another point to which he desired to direct attention was the difference in the methods of construction employed in America and in England. In the former country a machine of some kind was apparently used for the removal of earthwork instead of men and horses, but no such machine was known here. With regard to Pullman's carriages, considered in the abstract the less dead weight there was to carry the better. If a carriage with a certain degree of comfort could be produced of a small weight instead of a large one, undoubtedly it would prove the more valuable article. But there was a certain attractive power about a Pullman's carriage, which ought not to be overlooked, a power which brought passengers to it who would not otherwise travel by railway. A Pullman's carriage weighed somewhat over 20 tons. The cost of hauling that weight was about 1½*d.* a mile; that was the sum which the Midland Company proposed to charge for first-class passengers, so that one first-class passenger would pay the haulage of the carriage. If the attractive power of the carriage brought more than one first-class passenger it would of course pay itself. He understood, from a speech recently delivered elsewhere, that the carriage had proved attractive, and that the Midland Company contemplated extending the system. He did not think a fair comparison could be drawn between one carriage and another without taking into consideration the attractive power of the carriage, or the comfort and luxury which it offered to passengers.

Mr. Bramwell said he gathered from Mr. Worsdell that it was customary in the United States to stay fire-boxes to the upper part of the semicircular roof of the boiler. (Mr. Worsdell said that when copper fire-boxes were used that was the case.) It was also stated that, on using steel boxes, the practice was discontinued, and reliance was placed on girder stays upon the roof of the fire-box, and that when, yielding to the representations of certain persons, one of the boxes was again stayed to the semicircular roof of the boiler, a disastrous result took place. During a discussion at the Institution on a Paper by Mr. Robinson on Locomotives, when that kind of staying came under observation, he

said,[1] and now repeated, that, to his mind, it was perfectly clear the staying-up of a fire-box to the semicircular roof of the boiler must of necessity put a strain upon the outer shell of the fire-box, and that a disastrous result ought to happen, he would not say an explosion, but the gradual and successive giving way of the side stays. These propositions were denied at the time, but it was admitted that stays had given way just in the place where he said they ought to give way. If there were a semicircular roof to a boiler, and the flat top of the fire-box were not stayed to it, the semicircular part of the roof was in balance, and the screw side stays would not be called upon to play any other part than to hold in the small superficies which each stay subtended; but by hanging up the roof of the box to the arch above it by radiating stays, the balance of pressure on the upper part of the boiler was taken off, and lateral strains were thus thrown upon the side stays, which they otherwise would not have had to bear; the result was that the top side stays, the screw stays, gave way, the top row first, then the next, and so on. He had always understood that this defect occurred in those cases where staying up to the roof of the boiler had been practised in England, and that it ceased to occur when girder stays were trusted to. He was not surprised to hear that the result of staying up one of the steel fire-boxes to the semicircular roof of the boiler was not successful. It seemed to him that it ought not to have been so, because, owing to the hanging up of the flat roof of the fire-box to the semicircular top of the boiler, the balance of pressure was destroyed.

Mr. Webb remarked that with fire-boxes rigidly stayed to the outer casing, when the fire was lighted in the engine, the internal box was the first to expand, and the effect of that was either to depress the crown, to bend the roof stays, or to force up the outer shell, thus contributing to create a groove along the longitudinal seam joining the crown-plate of the outer casing to the side plates. The plan adopted at Crewe was to sling the fire-box to the outer casing in such a way, that though the fire-box could expand upwards, when the pressure was in the boiler, the fire-box roof was well supported and could not come down.

Mr. Michael Longridge thought that information about American railroads must be particularly interesting because of the great difference between the systems in the two countries; and any facts that would contrast the two systems, so as to indicate which should be employed in a particular case, could not be other-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 26.

wise than useful. In some cases there could be no choice. No engineer would establish what was known as an American railroad to carry the vast traffic of this country at the high speeds now required; nor would it be possible in a place like South America to raise the capital required to build works of the same solidity as those constructed in this country. The colonies could raise money at 5 or 6 per cent., and the Indian Empire at 4 or 5 per cent., and then it became a question for an engineer to determine whether it was better to pay 5 or 6 per cent. on the extra cost of heavier rails, greater quantity of ballast, and a more enduring road, or to bear the increased cost of maintenance of an inferior line. It appeared from Table I. that the percentage of working expenses to gross earnings for thirteen years was 65 per cent. In Sweden, a country where the traffic resembled that of North America, and where the climate was similar, the proportion on the State lines was about 53 per cent., and on many other lines lower, being in the case of the Gefle-Dala as low as 38 per cent.[1] The

[1] The following particulars of the working expenses and other details of the Swedish railways, in 1870, have been furnished by Mr. Michael Longridge:—

TRAFFIC.

Name. Gauge 4′ 8½″.	Length of single line.	Average Cost per Mile.	Engines.	Carriages.	Wagons.	Train Mileage.	Passengers.	Tonnage.
	Engl. miles.	£.	No.	No.	No.	English miles.		
State Railway .	694	7,470	102	320	2,431	1,732,369	1,593,141	712,505
Gefle-Dala . .	57	6,797	17	19	615	240,744	112,750	429,010
Total of lines on above gauge	927	6,960	144	428	3,483	2,341,255	2,260,805	1,582,729

The average receipts per passenger per mile were . . . . 0·677*d.*
,, ,, ton of goods were . . . . . 1·155*d.*

RECEIPTS.

Name.	Passengers.	Luggage, Horses, Carriages, Dogs, &c.	Goods and Cattle.	Miscellaneous Receipts.	Total Receipts.
	£.	£.	£.	£.	£.
State Railways .	140,176	12,059	224,475	5,337	382,047
Gefle-Dala . .	6,370	523	77,227	821	84,941
Totals . .	170,013	14,848	349,088	9,072	543,021

Swedes, however, paid particular attention to ballasting. He supposed that the large proportion of 65 per cent. on one of the best lines in the United States was in a great measure due to the heavy

EXPENDITURE.

Name.	Permanent Way Department.	Locomotive Department.	Traffic.	Miscellaneous Expenses.	Total Expenditure.	Net Receipts.	Proportion of Working Expenses to Gross Revenue.	Percentage on Capital.
	£.	£.	£.	£.	£.	£.		
State Railways	56,758	78,308	58,827	9,224	203,117	178,930	53·2	3·5
Gefle-Dala .	10,098	12,678	7,079	2,246	32,101	52,840	37·9	13·6
Totals .	76,433	107,387	75,030	15,996	274,846	268,175	50·6	4·0

ANALYSIS OF TRAFFIC PER MILE.

Name.	Receipts.					Expenditure.				
	Passengers.	Luggage, Horses, Dogs, Carriages, &c.	Goods and Cattle.	Miscellaneous.	Total per Mile.	Permanent Way.	Locomotive Department.	Traffic.	Miscellaneous	Total per Mile.
	£.	£.	£.	£.	£.	£.	£.	£.	£.	£.
State Railways	201·9	17·4	323·4	7·7	550·4	81·8	112·8	84·8	13·3	292·7
Gefle-Dala .	111·6	9·2	1,352·5	14·3	1,487·6	176·8	222·0	123·8	39·4	562·0
Totals .	183·4	16·0	376·6	9·8	585·8	82·5	115·8	80·9	17·3	296·5

ANALYSIS OF TRAFFIC PER TRAIN MILE.

Name.	Receipts.					Expenditure.				
	Passengers.	Luggage, Horses, Dogs, Carriages.	Goods and Cattle.	Miscellaneous.	Total per Train Mile.	Permanent Way.	Locomotive Department.	Traffic.	Miscellaneous	Total per Train Mile.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
State Railways	19·42	1·67	31·09	0·74	52·92	7·86	10·86	8·15	1·28	28·15
Gefle-Dala .	6·34	0·52	76·99	0·82	84·67	10·06	12·64	7·06	2·24	32·00
Totals .	17·43	1·52	35·78	0·93	55·66	7·83	11·01	7·69	1·64	28·17

cost of maintenance of way and rolling stock. He wished that some details of the heavy working expenses had been given. The amount of dividend was much below the net revenue, and he could only suppose that the balance was interest on bonded debt. There were no particulars of the amount of bonded debt from year to year, the number of miles opened, and the equivalent of a ton, which he believed in America was sometimes 2,000 lbs. With these additions Table I. would give the first cost of the line, the cost of maintenance, the traffic earned, and the train mileage—data sufficient to enable a judgment to be formed of the economy of this line relatively to others. With regard to the snow fencing, that was a practice extensively adopted in Sweden, and the cost of a snow fence was often paid for in a single snowstorm.

Dr. SIEMENS hoped Mr. Fox would further explain the statement that, for the whole of the rolling stock in America, chilled cast-iron wheels were used in preference to steel-tired wheels. It was not said that this was done on the ground of economy; but that the steel tires had been tried for passenger cars, and that they quickly became dangerous from rapid wear. It seemed extraordinary that wheels with steel tires should wear so rapidly on American lines, as to become positively dangerous after a short service, whilst in this country chilled cast-iron wheels, which were formerly used for coal wagons and rolling stock of that description, had been abandoned on account of the dangerous character attaching to them. He thought this difference must be owing to some peculiar mode of manufacture, or to circumstances that had not been explained. He believed the outer rail on curves on American lines was not raised above the inner rail; and it might be that a wrench was thus imparted to the wheel in going round a curve which tried steel tires more than it would try a solid wheel. Reference had been made in the Paper to the use of steel for structural purposes. Steel boilers were general, and stress was laid upon their being made of crucible steel. For the shell of a boiler, he could understand that crucible steel would answer extremely well, because it was relatively hard, and tensile strength was the highest desideratum for the shell of a boiler. It was different in the case of a fire-box, where extreme toughness was the desideratum; and he should imagine that the crucible was not the best mode of obtaining that degree of ductility, since it would be obtained at the expense of strength. It had already been explained that the statement, with regard to the ductility test, did not apply to the steel which, when tried for tensile strength, gave a result of 90,000 lbs. That certainly would appear to be excessive

for steel that took no temper. Steel that would bear a tensile strain of 90,000 lbs. to the square inch would, when chilled red-hot, become hard to a certain extent, so that it could scarcely be the same steel that stood the two tests. With regard to the carbon, the figures quoted by Mr. Worsdell must, he thought, be too low. A percentage of 0·18, or even of 0·25, was a very low amount of carbon, even for the mildest steel. But one point ought not to be lost sight of, namely, that carbon alone did not determine the hardness of steel, but carbon and manganese. Steel might be made almost devoid of carbon, which would, nevertheless, possess a certain amount of hardness if plenty of manganese were employed. On the other hand, if very little manganese were used, considerable ductility would be obtained, even with 0·5 per cent. of carbon. Speaking from recent experience by Mr. Willis, the chemist at the Landore Steel Works, he believed that it was the sum of the two ingredients which determined the ductility of the steel. Without manganese as an alloy mild steel would break to pieces. If manganese appeared in excess, the steel became hard, and would not stand a blow. Steel was a material capable of being developed into almost any quality; it required, therefore, to be studied from various points of view. It was on such occasions as the present that its application, its usefulness, and its qualities for structural purposes became gradually more and more understood.

Mr. Galbraith said the first point that attracted his notice in the Paper was the dimensions given for the earthworks. Embankments for a double line were said to be 24 feet 3 inches wide at formation level: but he thought there must be an error in the statement. It would allow only 12 feet for the embankment of a single line of 4 feet 9 inches gauge. He had been trying to reduce the expenditure on railways, and he had found that a 15-feet base for an embankment was too small. On the other hand, cuttings with a base of 32 feet seemed extravagant. On first-class railways in England the cuttings were about 30 feet, and sometimes only 28 feet. He could not understand why a cutting should require a width of 32 feet, and an embankment only 24 feet. The permanent way of the Pennsylvania railroad was thought to be unusually strong, and about the best in America; but, compared with an English line, it was rather weak. Its strength was due to the great number of sleepers, which were placed about 2 feet apart. Timber was probably very cheap in America, and it suited the authorities to use a number of sleepers. The system would not answer for England, for sleepers were perishable, and it

was better to have a smaller number of them and a heavier rail. 'Shimming' appeared to consist in drawing spikes and putting a loose packing under the rail for repairs during frost; but he did not understand why it should be necessary, because, if the road was in tolerably good order before the frost, the sleepers ought to be set so hard in the ground that there could be no subsidence. On the other hand, if the 'shimming' was a customary process, he thought the spikes, from constant drawing, would soon work loose, and the road cease to be a good one. Dog-spikes were first introduced in this country with the Vignoles rails, but they had long since been abandoned as an inferior mode of fastening the permanent way. With regard to the general cost of construction, seven years ago, when it was found that railways cost so much and that dividends were falling, there was a great demand for light railways. About that time a clause was inserted in an Act of Parliament for the purpose of permitting the Board of Trade to sanction railways of a lighter description than those in ordinary use. After the Act had passed, it fell to his lot to construct two such railways. One of these was the Ilfracombe line, the gradients of which were heavy. It had been sanctioned in the previous year, but the cost seemed likely to be so great that, after the Act had been obtained, the promoters went to Parliament a second time, as the only way of getting the line constructed appeared to be by adopting the light system. He took the precaution to go to the Board of Trade in the first instance to ask about the permanent way, and was told by one of the principal inspectors that the Board would probably not be inclined to pass a less weight of rail than 60 lbs. per yard. Acting upon that, the construction of the railway was proceeded with. A steep hill interposed between the sea and the main system, over which the line had to be carried. There was one gradient of 1 in 40 for $3\frac{1}{2}$ miles on one side of the hill, and another of about 1 in 36 for the $2\frac{1}{4}$ miles on the other side. The curves were of 15 chains radius, one or two of 14 chains, and two, not on a steep gradient, of about $7\frac{1}{4}$ chains. The permanent way was laid with 60-lb. rails, with the sleepers, a yard apart, 9 inches by $4\frac{1}{2}$ inches. Great economy was exercised, and the works were let, including stations, for £90,000; but, when the Government Inspectors were consulted, the requirements with regard to stations were so increased, that the idea of a light railway soon disappeared. The signals, stations, and everything connected with the railway were as costly as though it had been a heavy one; the only thing light was the permanent way, and in order to get

that, restrictions were placed on the weight of the engines and on the speed. The result of this Ilfracombe experience indicated that a light railway in a hilly country was a mistake. The engines were specially built to suit the gradients: they had six wheels coupled, and weighed 24 tons. The wheels were 4 feet 6 inches in diameter, and the cylinders 16 inches diameter with a length of stroke of 20 inches. The greatest load that an engine was capable of taking up the incline was 84 tons; but it usually worked with a load of 75 tons. Soon after the line was opened, it was found that the permanent way was not suitable for engines of that class, which burst the rails out of gauge on the sharp curves, so that they had to be secured by ties. He thought that light railways, in this country, were only available where the gradients were easy and where light engines could be used. The easy railways in England were mostly made, so that he thought there was no great prospect for such projects. The cost of the Ilfracombe line, including land and all other expenses, was £135,000, being at the rate of £9,000 per mile. The other light line he had constructed was the Sidmouth railway, where the works were lighter and the gradients less steep, namely, 1 in 45 and 1 in 54. There was the same kind of permanent way, the same class of engine, and with the same results to the rails. The engine was apparently too stiff for the permanent way, although it was secured with better fastenings than appeared to be in use on the American lines. The South-Western Railway Company, who worked the Ilfracombe line, were persuaded to substitute the 75-lb. double-headed rail for the light permanent way on the two steep gradients above mentioned, and the result was satisfactory. He felt certain that if light rails had been adopted on the heavy inclines, considering the break power required, they would have stood but a short time. In the case of straight lines or easy curves, an engine did not do much damage to the permanent way; but with sharp curves and heavy inclines he was sure the system would not answer. One or two points were omitted in the Paper which would have helped to demonstrate the comparative cost of American and English railways. It was stated that the Pennsylvania railroad cost £11,250 per mile including rolling stock; but that sum ought to be divided under three heads, works and stations, land, and rolling stock, for the purpose of comparison. In America many items did not appear at all. There was no fencing; there did not seem to be any road bridges, level-crossing gates, or signals; the terminal stations were few; and last, but not least, there was no Government inspection. An American railway seemed to consist of the

line only. If there were a Government inspection, it was very different from what it was in England. Government inspectors were very courteous in their dealings; but he thought they were a little hard on the smaller class of railways. No expense should be spared in providing the most complete and the most perfect system of signalling which could be devised for main through lines like the London and North-Western; but in the case of branch railways, where every train stopped at every station, an elaborate system of signalling, to prevent one engine coming into collision with itself, seemed out of place. Bogie engines offered some advantage, and he should have been glad if they had been tried on the Ilfracombe line, or if radial axles had been introduced. The present engine ran round a 7½-chain curve on the heavy permanent way without doing any damage; and he believed that the mischief was due to the lightness of the road and the insufficient fastening, which a light rail rendered unavoidable.

Mr. Price Williams said this Paper supplemented two very valuable communications by the late Mr. Zerah Colburn, read before the Institution, some years ago. The classification of locomotives had then been treated most exhaustively, and not only had the types been given, but also the performances of different engines. Having regard to those statements and figures, he could not understand the assertion in the Paper about the evaporative power of an engine on the Altoona incline. The highest performance of one of the London and North-Western express engines with the Holyhead train was to evaporate 2,500 gallons in two hours. Mr. Colburn first drew attention to the subject of cast-iron wheels, and gave several striking results of their use. He expected in the interval that had elapsed some further valuable information and data would have been afforded. The Authors had, he considered, abundant materials for most important additions. Table I. appeared to him rather meaningless. It stated that the working expenses in the year 1873 amounted to 62 per cent. of the gross earnings, as compared with 53 per cent. for the United Kingdom according to the Board of Trade returns. The striking disturbances in the working expenses over the period covered by the Table did not seem to have been noticed. Thus in 1861 they were 50 per cent.; in 1862, 53 per cent.; in 1863, 57 per cent.; in 1864, 72 per cent.; in 1865, 76 per cent.; in 1866 they amounted to 77 per cent.; in 1867, 74 per cent.; in 1868, 69 per cent.; in 1869, 71 per cent.; in 1870, 64 per cent.; and then there was a gradual descent to

62 per cent. No allusion was made to the causes which had produced these large working expenses; nor were there any particulars of the mileage of new lines opened in the different years. What alone was given was the train mileage, which had increased from 4,000,000 to 16,000,000 in thirteen years; but no reference was made to the traffic per mile. If the passenger traffic and the goods traffic had been stated, a better means of comparison would have been afforded. Allusion had been made to a traffic diagram which he exhibited during the discussion last session upon Mr. Rapier's Paper on "The Fixed Signals of Railways;"[1] but its meaning did not appear to have been quite understood. It was not exhibited as a new invention. Mr. Harrison, the President, had stated that, years ago, he had been in the habit of using them, and Mr. Price Williams had employed them for twenty years. The diagram was produced merely to illustrate the particular point to which he was then referring, namely, the growing necessity for separating slow from fast traffic on the principal main lines of railway in this country.

Dr. Pole thought it would be interesting to know something more in detail of the permanent way arrangements on the American lines. The flat-bottomed or Vignoles rail, universally adopted there, was now fast superseding other forms, and was largely in use in every country except Great Britain. He had lately been over some portion of the district of the Chemin du Fer du Nord, in France, and found that all relaying was now done with that form of rail. Hence it was desirable to know the results of American experience with it, particularly as to the fastenings. The usual fastening was the simple dog-spike, but as this in soft wood sleepers was not so secure as could be wished, being liable to draw, it was often customary to use fang-bolts in addition, which were troublesome things. He had found that the French, instead of dog-spikes, were using wood screws, which answered very well, and rendered the addition of fang-bolts unnecessary. His attention had been directed to the great holding power of wood screws, some years ago, when he was on the Iron Armour Plate Committee. He had noticed, at Cherbourg, that the French fastened their armour plates to the timber ships by large wood screws, instead of by bolts and nuts as in England, and he obtained from the Admiralty permission to erect at Shoeburyness an experimental target on this principle. It was tested by being fired at with heavy ordnance, when the holding power of the wood

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxviii., pp. 231–237.

screws proved very remarkable; for after the target was smashed to pieces, many of them were found still holding fragments of plate to the corresponding fragments of timber. The wood screws, therefore, seemed to him so good a fastening that he had adopted them for some flat-bottomed rails he was laying down, adhering as nearly as possible to the French model. The holding power had been tried and was found to be much greater than that of spikes of much larger size, even when the latter were newly driven, and held best. The wood screw was by no means a new fastening, but it was little used, not so much as he thought it ought to be. Its expense was not greater than that of the dog-spike, for although it cost more per ton, this was compensated for by its being lighter. He had taken some pains to inquire whether any objection had been found to it, and the only one he could hear of was the difficulty of preventing the platelayers from driving the screw in with a hammer, to save time, when the inspector's back was turned; that, however, he hardly considered an insuperable objection. With such a fastening, the flat-bottomed rail, on cross sleepers, and with suspended fish joints, formed a very good road, and of great simplicity, both for laying and maintenance.

Reverting to the subject of the cast-iron wheels, which was one of great interest, he conceived there must be something in the quality of cast iron, as used in America, not known in this country. Messrs. Fox had mentioned a strength much higher than was usual here; and he believed their statement was corroborated by other facts. He had had occasion, when compiling some data on iron, to refer to a remarkable series of American experiments on cast iron as used for guns, and which were published in full detail by the American Government in 1856.[1] The tenacity in these was found in some cases to be upwards of 15 tons, and in one case as high as 20 tons; this being obtained, not only by the intrinsic quality of the metal, but also by its peculiar treatment in the founding.[2] Some progress was being made in England in the improvement of cast iron. It had lately come to his knowledge, that a firm in the Midland Counties were undertaking the manufacture of large articles in malleable cast iron, a material long known as of much value from its toughness, but the use of which had been hitherto confined to small Birmingham hardware. Still,

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[1] *Vide* "Reports of Experiments on the Strength and other Properties of Metals for Cannon." By Officers of the Ordnance Department, U.S. Army. 4to. Plates. Philadelphia, 1856.

[2] *Vide* "Iron as a Material of Construction." By William Pole, F.R.S. London, Spon, 1872, pp. 79, 80.

however, this would not bear chilling, and therefore it lacked one important requisite for railway wheels. Great Britain ought not to remain behind America in this matter, and it would, he conceived, be well worth while for enterprising ironfounders to direct their attention to the subject, and, if necessary, to procure samples of American pig iron for trial, and to imitate the foundry manipulation there adopted.

With regard to steel, it had been stated that one of the tests applied in America was to heat the plates red-hot and then to dip them in water, after which they must retain their softness and malleability. But he would ask, was such a material really steel? He thought not. What was the definition of steel? Chemically, no doubt, the proportion of carbon might be a test; but for the practical worker in metals, the most common characteristic of steel was its capability of hardening and tempering; and if this no longer existed, the metal was scarcely entitled to the name. He believed that much of the metal now manufactured so largely in this country by the Bessemer and other new processes, was not true steel, but rather iron under another name. No doubt it had advantages over ordinary iron, in its homogeneity, its freedom from the flaws and defects often due to piling and welding, and so on, but still, when made in the mild ductile quality now so much aimed at, it had not the salient metallurgical characteristics of hardness, tenacity, or temper, which were generally attributed to steel.

The views of railway authorities with respect to the Pullman cars might differ, but he thought, that, at least, those who had travelled in them might fairly bear testimony in their favour, as compared with ordinary vehicles. Notwithstanding the vast improvements in travelling facilities in the present day, it must be admitted, that a long railway journey in an ordinary English carriage still involved some discomfort from the compulsory detention in such a confined space. In the Pullman car the traveller might move about in spacious and comfortable rooms, ventilated in summer and warmed in winter, and provided with many nameless conveniences that were out of the question in ordinary railway conveyance. The motion, too, in such long carriages, was so much smoother, that (as had been his own experience) a business man might, if the road was in good order, sit at a table and write without difficulty. In fact, with these cars, the traveller might fly through the country at 40 or 50 miles an hour almost as comfortably as if he were in his own house, and this was surely a result worth attaining. He once

heard a clergyman say, in opposition to the modern stiff-backed benches, that if it would induce people to come to church, he would willingly give them cushioned arm-chairs; and, on the same principle, if people were to be induced to travel, it might not be inexpedient to make travelling pleasant for them.

Mr. Walmsley Stanley observed that he had been engaged in constructing railways in Sweden, a country somewhat similar to America. The ordinary formation width of embankments was 18 feet. The lines were all single, built with flat-bottomed rails placed 4 feet 8½ inches apart. His experience was different from Mr. Galbraith's with regard to railways of light construction. Upon the railways he had constructed, some of which had been opened for three years, flat-bottomed rails were used of 60 lbs. weight, 4¼ inches wide by 4¼ inches deep, placed upon pine sleepers 2¾ feet apart from centre to centre, except at the joint, where they were 2 feet from centre to centre, the joint being suspended. There were gradients of 1 in 60 for 3 miles; and, owing to the difficulties of the country, the line was curved nearly from end to end, the radius of the sharpest curve being 1,400 feet. The engines weighed 30 tons, the pressure upon the front axle being 11½ tons. There had been no cutting into the sleeper and no drawing of spikes, although the traffic had been heavy; and yet only 1 per cent. per annum was due to renewals, while the working expenses had not exceeded 43 per cent. The lines were all under the supervision of Government inspectors, who were, if anything, more strict than in England. The construction would well bear comparison with that of the best lines in this country, and the rolling stock was, on the whole, superior. Dog-spikes, to attach the rails to the sleepers, were universally used, and suspended joints. On the States lines a solid joint was first tried, the rail lying on a flat bed plate over the centre of the sleeper, but this had been abandoned, owing to the damage caused to the ends of the rails. An objection to the screw, to which reference had been made by Dr. Pole, was, that it was difficult to get out. The dog-spike could be quickly withdrawn and driven in again at the same place from whence it was taken out, and it would hold the rail almost with the same tightness as before. A portion of the sleeper must be destroyed when the screw was used; and in many cases it would be necessary to drive in the screw to save time in case of accident; and although it might make a good road in the beginning, after a few years it would be difficult to adjust. Shimming, or packing with wood wedges, was absolutely necessary in very cold countries, where the road froze

4 or 5 feet deep in clayey spots and in ill-drained rock cuttings. On such occasions the ground rose several inches in hummocks, and then the choice lay only between cutting down the sleepers on such hummocks, or packing the rails for a distance on each side. Good deep coarse ballasting was absolutely necessary in such places, but where there were alternate thaws and frosts packing became necessary even with the best ballast.

Mr. PHIPPS said that cast-iron wheels had been alluded to in almost every aspect except that of safety. In this country, during a severe frost, there were numerous instances of breakage of wheels; and it was worth while to consider in what respect cast iron was less likely to break under such circumstances than wrought iron. Cast iron was usually regarded as a substance exceedingly brittle, notwithstanding that it was so much more extensible than wrought iron. The tires of existing wheels were shrunk-on often almost to the verge of breaking, it being merely by the judgment of the workman whether they were sufficiently tight; and, supposing a certain amount of heat to pass at any time into the boss of a wheel from the heating of an axle the spokes would expand, and induce rupture of the tire. With a cast-iron wheel made of one piece there was no shrinking-on of the tire, and there was greater extensibility of the iron—elements which tended to the prevention of accidents.

Mr. SHELFORD had listened with great interest to the remarks of Mr. Galbraith and Dr. Pole on the question of the permanent way, as he was desirous of making light railways. He believed a committee of the American Society of Civil Engineers had reported during the present year upon the manufacture, form, and endurance of the Vignoles rail, and one of the conclusions arrived at was that the best form was a base of 4 inches and a depth of $4\frac{1}{2}$ inches, with a web of not less than $\frac{1}{2}$ inch thick. These dimensions nearly corresponded with those given in the Paper. The weight of such rails would be about 62 lbs. or 65 lbs. per yard, and he believed they were fastened by dog-spikes to hard wooden sleepers. Very much the same form was, he understood, used on the State railways in Germany, where the rail had a depth of $4\frac{1}{2}$ inches and a base of $3\frac{3}{4}$ inches, and weighed 62 lbs. per yard. It was fastened to hard wood sleepers by dog-spikes, and at each side of the joint there was a rolled iron sole-plate through which the dog-spike passed. In this country such a method would be impracticable, because the sleepers were of soft wood. He had laid a Vignoles rail, which had lasted in constant use for eight years, and now carried fifty trains a day. It

had a base of 5½ inches, a depth of 4½ inches, weighed 75 lbs. per yard, and had stood very well. If the base was reduced much below that it was impossible on soft sleepers to get a good fastening, or one which would pass a Board of Trade inspector. That was a matter of interest at the present time, since a considerable and perhaps increasing mileage of branch lines was being constructed upon working arrangements with the parent companies. It was the interest of the constructing company to make as light a road as possible, while it was the interest of the parent company to get a good and perhaps expensive road. His experience of the working of the first light railway constructed in Wales, under the Act referred to, coincided with that of Mr. Galbraith.

Mr. W. B. Lewis asked what was the width of the base of the rail on the Ilfracombe line. He had been engaged in laying a length of 15 miles of railway in Ireland, with rails 5¼ inches wide at the base, and these carried heavy engines without difficulty.

Mr. Galbraith said the base was 4 inches and the height 4½ inches. He had no hesitation in saying that a base of 4 inches was too small.

Mr. J. Fernie said he had been over the Pennsylvania railroad, and had witnessed many experiments on the steel to which reference was made, some specimens of which he exhibited. He had also seen chilled wheels cast at one of the best known works established for that purpose in Philadelphia. He was not only shown the process of manufacture, but also the pig iron used, and he thought the observation made by Dr. Pole was correct—that the high quality of the steel and of the iron castings in America was owing to the excellent pig iron employed, as well as to the great care exercised in casting. The following statement, of the pig iron made in the United States during the year 1872, was extracted from the Statistical Report of the National Association of the iron manufacturers of the United States:—

	Tons.
Pig iron made with coke and coal	712,500
Do. do. anthracite	1,197,050
Do. do. charcoal	478,750
Total	2,388,200
Pig iron imported from Great Britain in 1872 .	190,000

From that return it would be seen that less than one-third of the quantity was manufactured with coke and coal, and this was equal in quality to the British iron imported, that about one-half was made with anthracite, some of which ranged in price about £5,

say 20*s*., per ton dearer, and that more than one-sixth was charcoal iron of the best quality. He was not prepared with similar statistics of the qualities of pig iron made in Great Britain; the total manufacture, however, in 1872 was about 7,000,000 tons. No doubt a large quantity of high-class pig iron was imported from Sweden, while a considerable quantity of cold-blast iron and of hæmatite iron of good quality was made and used in this kingdom.

In considering the quality of the iron manufactured in America, reference ought to be made to the character of the fuel. Large quantities of anthracite were consumed in all branches of the iron trade, and he had no idea of the purity and excellence of this material until he had seen it in the great colliery districts on the Philadelphia and Reading, and the Lehigh Valley railroads. The supply of this fuel was practically inexhaustible, and it was used not only for smelting iron, but also for puddling and reheating it. He had likewise seen cast steel melted in crucibles with anthracite coal instead of coke. This anthracite was won in large blocks, and was very hard. In the colliery he examined it was raised about 50 feet above the ground, and was passed through a series of crushers, which broke it up to the different sizes required. While passing from one crushing-machine to another it was carefully examined, and all impurities picked out.

An English engineer, visiting the United States, thought it extraordinary to see car wheels of cast iron. Contrasting the English complicated wheel, with its wrought-iron centre of many parts welded together, and a tire shrunk on tight, with the simple American chilled wheel, he was induced to think the Americans were in advance of this nation. From the humblest wagon to the most sumptuous Pullman car, all were fitted with the simple chilled wheel. On inquiring as to the manufacture of these wheels, he found they were not made in ordinary foundries, but in special manufactories. The moulding boxes were of simple construction; the outer rim and flange of the box consisted of a heavy metal chill; the other part of the pattern was rammed up in sand, dried in a stove; and the metal—a mixture of worn-out wheels, anthracite iron, and charcoal iron—was carefully melted in an air-furnace, and poured into the mould. When the metal was sufficiently set, the casting was taken to an annealing oven, where it remained several days, and slowly cooled, after which it was bored out, pressed on the axle without any key, and was forthwith ready for use. These wheels were even employed as the leading wheels of engines. Through the courtesy of the late President of the Company, Mr. Edgar Thomson, he had gone

through the works at Altoona, and had witnessed the various operations connected with locomotive repairs and rebuilding, in which there was nothing special, but the carriage department was excellently arranged. At Altoona, he was particularly struck with the manufacture of the boilers, and with the steel of which the fire-boxes were made. He exhibited a specimen of boiler plate which had been made red-hot, then dipped in cold water and bent round flat, and it was without a flaw. Being so much pleased with the steel, he visited the maker, Mr. Parkes, at Pittsburgh, who received him most kindly, and he obtained a good deal of information from him. The steel was made of a mixture of charcoal and anthracite iron, and was cast in a plumbago crucible, two heats per day being obtained. He had not been able to apply any delicate chemical or mechanical tests to ascertain the quantity of carbon it contained, or its tensile strength per square inch; but he had, both with Mr. Worsdell at Altoona, and Mr. Parkes at Pittsburgh, tested it severely by bending and re-bending, and by heating and cooling it rapidly, and under all these changes it appeared perfectly adapted for fire-boxes.[1] For the purpose of this discussion he had re-tested a piece: he had nicked each end with a file; he then hardened one end, and bent each end over till they broke; the result was that the hardened end broke a little sooner than the other, but the difference in hardness was not perceptible when tested by a file; the centre-piece was afterwards bent quite flat, and was without a flaw. The maker said that, after the plates were rolled, they were dipped in a large vessel of cold water, and if they came out uninjured they were good plates. Afterwards the edges were sheared, and the plates were tested before being

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[1]

	Krupp Steel.*	American Steel.†
Carbon, combined . .	1·18	0·23
Silicon.	0·33	trace
Sulphur	none	none
Phosphorus	0·02	0·05
Manganese	trace	none
Cobalt and nickel . .	0·12	..
Copper.	0·30	..
Iron, by difference . .	98·05	99·72
	100·00	100·00

* *Vide* "Metallurgy, Iron and Steel," by Dr. Percy, p. 837.

† From an analysis Mr. Siemens recently had made of a piece of this steel.

sent out as finished. Mr. Fernie had not seen steel of that particular quality in England. For the manufacture of cutters, axes, taps, dies, and articles of that kind, the makers said they obtained the best steel from Sheffield; but they manipulated it very cleverly, and were able to send to this country tools with which the Sheffield people had not yet been able to compete.

In his travels through the United States what he saw in regard to mechanical engineering work was of the best kind. All appeared to aim at perfection, and no expense was spared in arriving at that result. Many revolutions in mechanical engineering had been introduced into this country from America, besides the Pullman car and the fare of 1½*d.* a mile, and he believed there was still a good deal to be learnt. The greatest facilities were afforded him for seeing everything in connection with the mechanical and engineering progress of the country, and he had invariably been received in the kindest and most courteous manner by all American engineers.

Mr. Berkley observed, with regard to the Pullman car, that he had no desire to interfere with the scheme propounded for promoting traffic, on a particular railway, by offering passengers a palace car at 1½*d.* a mile; but there appeared to be an impression that the railway company would not lose by the transaction. Now he wished to show, by facts and figures, that the anticipations of a more general use of the Pullman cars were not likely to be realised. An ordinary first-class carriage, which, as usually made, was moderately comfortable, would accommodate about as many as the Pullman car, namely, twenty-four passengers in comparison with twenty. It cost on an average £650, while a Pullman car cost £3,000. It weighed 8½ tons in comparison with 20 or 24 tons. He maintained that it was better to provide the best possible accommodation for the many at the least cost, and by the most scientific appliances, than to provide special luxuries for the few at a great cost. When in the United States, eight years ago, he was specially struck with the fact that the railroads first made to meet the very limited demands of American society, were being improved as the requirements increased. These improvements consisted in the introduction of steel or heavier iron rails, of iron bridges instead of wooden bridges, larger engines, better rolling stock, new and larger stations, and the like. He had, therefore, hoped to learn something from the Paper of the history of those improvements, especially in connection with the Pennsylvania Central railroad, which had been called the London and North-Western of America. He had looked in vain for that kind of information. It should not be forgotten

that in England a comparatively small proportion of railways consisted of single lines, while in America the proportion of single lines was very great. He was surprised to find it stated that the cost of the Pennsylvania railroad had only been £12,310 per mile for the whole system, and £11,250 for the main line. On that subject he had consulted the "Report of the Investigating Committee," appointed so lately as the 10th March in the present year, with the concurrence of the directors (a circumstance that might be commended to the notice of English railway companies), to investigate the position of the company in every respect. The Committee had therefore the services of the directors and of the whole of the staff in making their inquiries. Under the head of "Cost of Main Line,"[1] it was stated, "By referring to the article on the cost of real estate, road, &c., you will find that your main line, including the Philadelphia and Columbia railroad with the present value of its equipment, real estate, &c. . . . . stands charged on your books at $48,571,808." That really amounted to upwards of £27,000 a mile, instead of the cost given in the Paper. He should have been much astonished if the result had been otherwise, considering the accommodation afforded, the many improvements introduced, and the summit to be ascended and descended. It was difficult to imagine that such a line could have cost less per mile than the average of the lines—most of them single—throughout the country. The sum mentioned did not include stores, but probably they should not be included in the capital. The report presented a comparison extending over ten years. As a similar comparison had been made in regard to English railways by Mr. J. Thornhill Harrison, M. Inst. C.E.,[2] it would be found particularly apposite and valuable.

On this subject the report stated:—

"1. That with an increase of $59\frac{466}{1000}$ per cent. of capital, there was a gain in tons carried one mile of $229\frac{49}{100}$ per cent., and a gain in freight earnings of $210\frac{42}{100}$ per cent., while the rate of compensation received for carrying one ton one mile was reduced from $2\frac{48}{100}$ cents to $1\frac{4159}{10000}$ cents per ton per mile, and expenses from $1\frac{89}{100}$ cents to $0\frac{857}{1000}$, and the profit per ton only from $0\frac{59}{100}$ cents to $0\frac{5589}{10000}$ cents per ton per mile; thus showing that while the charge for moving freight was reduced $1\frac{641}{1000}$ cents per ton per mile, the expense of doing the work was reduced $1\frac{33}{1000}$ cents per

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[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxix., p. 322 *et seq.*

[1] *Vide* "Report of the Investigating Committee," &c., p. 98.

ton per mile, and the profit was only brought down $\frac{311}{1000000}$, or one-third of a mill per mile per ton.

" 2. The passenger travel will not, of course, show such favourable results, as the outlay on the road was mainly to carry freight; but it shows, as between 1864 and 1873, that with an addition to the capital of $59\frac{460}{1000}$ per cent., the passenger travel has increased $20\frac{44}{100}$ per cent., and the cost of carrying one passenger one mile from $1\frac{92}{100}$ to $2\frac{7}{100}$; while the net earnings have decreased from $0\frac{70}{100}$ to $0\frac{47}{100}$ cents per mile."[1]

It was also stated "that for every million dollars invested since the year 1863 there has been an increased annual profit of $280,000, taking your profit in 1873 as a basis."

With regard to the introduction into other countries of the American system of constructing railroads, that introduction would be advantageous or disadvantageous according to the circumstances of the case. There were some countries where it would be difficult to make temporary lines, because the requisite materials could not be readily obtained; and there were demands upon the railways that were not consistent with the working of such temporary lines.

Mr. E. A. Cowper considered it particularly desirable to have all the fully-proved facts resulting from such large experience as the Americans possessed; as, for example, in the simple matter of chilled cast-iron wheels. Something about them was known here; tens of thousands had been made and used, but, for the most part, only under contractors' wagons or coal-trucks, because they were considered dangerous. He believed they were formerly dangerous even in the United States, long after they had been adopted for bogies both to engines and carriages. But the Americans had given great attention to the process of casting such wheels, and to the metal of which they were made, and in this respect they had the advantage in being able to choose first-class iron for the purpose, and iron that would chill deeply. That was important; for some iron would not chill deeply. He had been informed on good authority that iron made from red hæmatite ore was not suitable for chilled wheels, but that the iron must be from the brown hæmatite ore. Another important point was to arrange the best way of cooling the nave of the wheel when cast. The nave, which was the heaviest part, was surrounded by heated metal and sand. He had made a hole through the bottom of the mould, to admit air, and removed the core as soon as possible; but that was scarcely satisfactory. The

[1] *Vide* " Report of the Investigating Committee," pp. 106 and 107.

usual plan was to divide the boss into four parts, and then to clamp the parts with two hoops; but this was a poor job. Further information about the mode of cooling or annealing the chilled cast-iron wheels would conduce to their introduction into this country, if it could be shown that they might be used with safety.

With regard to steel boilers and the steel tires of driving wheels, he had been pleased to hear the remarks of Mr. Worsdell, and of one of the chief pioneers in the introduction of steel into boilers, ships, and engines, Mr. Webb; and he should have been glad if the practical result had been disclosed of the use of steel of mild or low quality in ships. It was not commonly known that 25 per cent. might be saved in the weight of a ship if built throughout of mild steel that would not harden, and that would not stand a greater strain than 30 tons per square inch; but such was the fact. He knew of a ship built of puddled steel, in the early times, when the proportion of carbon was irregular. After the smiths had thinned down the corner of a plate they used to quench it; but this led to some of the corners dropping off like fractured glass, from the hardening produced by the quenching; and it was found that the only way of preventing this was by the removal of the water boshes. Now, however, with mild steel, having a percentage of less than 0·3 of carbon in it, a saving could be effected, as before mentioned, of 25 per cent. of the weight of a ship. With regard to the trial of steel, either made by the Bessemer process or the Siemens process, he had designed a simple plan of obtaining a better knowledge of the metal than by breaking it, namely, by filing. Having heated and quenched a set of samples of steel, he took three common hard saw-files, and lowered the temper of one to a straw temper and of another to a blue temper, and tried the two sets of samples, and it was astonishing to find how this extended the power of examining steel. Hard-drawn pianoforte wire would often stand a tension of 75 tons per square inch; and he had made some very hard, that endured 130 tons, but that was too hard for use. He should like to inquire whether in cast-iron valves slight recesses were made in the under side or face of the valves to harbour steam. This, he believed, was important, and was said to result in an improvement in the working of slide valves.

Mr. C. D. Fox, in reply upon the discussion, said no one could feel more strongly than himself the importance of basing all Papers brought before the Institution on facts. To that end the Company had furnished him with special reports by its chief officers, and upon the figures contained in those reports the Paper was based,

so far as related to the Pennsylvania railroad. The general information was the result of five separate visits to the United States. He had purposely slurred over the question of cast-iron wheels, and other matters, to which reference had been made, because they had been thoroughly discussed on former occasions; and he tried to lay stress on points not then dwelt upon. One of these, the rapid extension of the railway system of the United States, was unparalleled in the history of railways, and might well be discussed both in regard to cost and general results. The committee of shareholders, whose report had been cited, stated a distinct opinion, that the western extension of railroads had reached a limit so far as it was dependent upon the shipment of grain to Europe; and it was an interesting question how to contrive to bring manufacturers to the grain merchants, so that they might live upon one another. Another point was the gradual consolidation going on in America, by which all the great routes, east and west, were getting into the hands of three or four of the larger companies. Another was the use of heavy rolling loads on a light permanent way. While English engineers were trying to reduce the dead weight, the Americans, by the introduction of the Pullman car and other expedients, had gone in an opposite direction. He thought sufficient consideration had not been given to the bogie truck, the effect of which upon railway construction was greater than might at first sight appear. It was a beautiful contrivance, for rough roads and sharp curves, that might be studied with advantage. Many minds in this country were busy upon the question of central coupling as against side buffers, and numerous inventions in connection with it were brought forward, some of which he found, on reference to the "American Mechanical Dictionary," were old affairs. He had been desirous of hearing something said on the American practice of so arranging the cross beams on bridges as to bring cross strains on to the top members. This was unusual in England, and he had exhibited a diagram (Plate 4) of a bridge which had been designed in America to meet the evil. In regard to the general cost of railway construction, and to the statements of the Investigating Committee, it should be remembered that the Pennsylvania Railroad Company was a body much resembling the octopus, having many arms, which it was difficult to divide from the head. Its own line was 355 miles in length, with 82 miles of branches distinctly connected with the main line; but it controlled 5,933 miles. He had analysed the cost of the main line and its branches, and the figures given in the Paper would, he believed, be found closely approximate. The Com-

pany, contrary to general practice both in England and America, had for many years resolutely refrained from adding to the capital account. It appeared from the report that, on a re-valuation of the land, works and rolling stock, not only had the two last named cost a great deal more than was indicated in the Capital Account, but that the land was worth three times its original cost. The result was that the railway cost £8,904,830, and was now worth £17,306,300; showing an increase of value of 94 per cent. on the capital expenditure. He had not been able to ascertain the number of miles opened annually. The total expenditure on railways in the United Kingdom in 1873 was 3*s.* 1½*d.* per train mile; that on the Pennsylvania railroad during the same period was 3*s.* 6¼*d.*; and in Sweden, during the latest year given—viz., 1870—it varied, according to Mr. Michael Longridge, from 2*s.* 8*d.* to 2*s.* 4*d.* The Swedish lines, he thought, did not offer a fair comparison either with English or American lines, and this was especially the case with reference to the Gefle-Dala line. The cheap working of the Festiniog line had been conclusively shown to arise from the peculiar nature of the traffic. The Gefle-Dala afforded a parallel case—the traffic being almost all downhill, and of a heavy class, whilst in addition the fuel was obtainable at a small cost. The policy of the Pennsylvania company was not changed, and all improvements were still being made out of revenue. The Committee of Investigation distinctly reported that they considered the Directors ought to pay regularly a 10 per cent. dividend, which had been hitherto done, and that a large sum ought then to be set aside annually to improve the works. No doubt many English companies would be glad to look at the matter in the same light. A considerable portion of the Pennsylvania system ran through a thinly-populated country, whilst the rates for the through traffic were kept down by severe competition, and these two facts might account to some extent for the high working expenses. These, in 1873, might have been expected to be abnormally high, and it spoke well for the management of the Company that the opposite was the case. In England they advanced from 49 per cent. in 1872 to 53 per cent. in 1873, owing to exceptional causes; those same causes were operating to a certain extent in America, and would not materially interfere with a fair comparison. With regard to the work done by the locomotives, the maximum cost per ton per mile was 1*d.*, in 1865. In 1873 it was a little over ⅓*d.* The passenger earnings were $1\frac{1}{10}d.$ per passenger per mile, and the expenses $\frac{9}{10}d.$, the net earning being ⅕*d.* The goods earnings were ⅗*d.* per ton

per mile; expenses, $\frac{1}{3}d.$; net earning, $\frac{1}{4}d.$ In making comparisons over a series of years, regard must be had to the fluctuating value of the dollar, which had varied from 1*s.* $9\frac{1}{2}d.$ in November 1864, to its present value, about 3*s.* 8*d.* The locomotives had not been classed by Mr. Colburn; and the classes which Mr. Fox had given were not his own, but the company's, and represented the number of types to which the locomotives had now been reduced.

A great deal had been made of the statement that a certain engine had evaporated 2,400 gallons of water in less than an hour, which was no doubt an extraordinary quantity. He had referred to the papers sent him by the Locomotive Superintendent, and found that the quantity was correctly stated. He had looked into the matter, with the kind assistance of Mr. William Adams, M. Inst. C.E., to ascertain whether it was impossible or not. Taking a grate area of 17 superficial feet, cylinders 17 inches by 24 inches, wheels 61 inches in diameter, pressure 140 lbs., 8 lbs. of water per pound of coal would equal 3,000 lbs. of coal per hour, or 176 lbs. per square foot of grate per hour, equal to 22 cubic feet of water per foot of grate. That, of course, denoted an intense but not an impossible combustion. Mr. Colburn had referred not unfrequently to a consumption of 100 lbs. of coal per mile, as against 45 lbs. or 55 lbs. in England. The actual run of the engine was 27 miles. Taking it as only 26, that would equal 92 gallons per mile, or 2·7 lbs. of water per revolution of the driving wheel. The following figures would show that the performance spoken of was by no means impossible:—

Capacity of cylinders at 140 lbs. pressure, cutting off at $\frac{5}{8}$ stroke (15 inches).

$$\frac{227 \times 15 \times 4 \times 62{\cdot}4}{1728 \times 179} = 2{\cdot}7 \text{ lbs.}$$

(specific volume of 140 lbs. steam).

Mr. Worsdell, although he still thought the work impossible, had sent an example of his own experience on the Pennsylvania railroad which was quite as remarkable. The engine in question was a 'mountain' one, cylinders 18 inches by 22 inches; wheels, 4 feet 7 inches diameter; total load, engine and tender, 60 tons, thirteen cars, 235 tons = 295 tons taken up the incline of 12 miles, with a maximum incline of 1 in 55, in fifty-nine minutes. The coal used was 2,750 lbs., equal to 160 lbs. per square foot of grate, or 229 lbs. per mile. This immense consumption was explained to be owing to the fierce exhaust and to the fact that much unconsumed coal went up the chimney. The amount of water evaporated was 1,620 gallons in the 12 miles. Five pounds of water were used per pound of coal, and the pressure of steam maintained in the cylinders was 112 lbs. A doubt had been expressed

whether the steel for the fire-boxes could be crucible steel. Mr. Fox believed that almost, if not all, the steel used in America up to within a short time was crucible, but that Bessemer steel was now being largely worked. The steel used for fire-boxes was certainly not the same as that adopted for boilers; but the difference was a secret not easily obtainable. The cold-water and bending test spoken of was certainly applied to fire-box steel $\frac{1}{4}$ inch thick. With regard to cast-iron wheels, there could be no comparison between the qualities of English and American cast iron, and a good deal of misapprehension had arisen from that fact.

The reason for cast-iron wheels having been so successful in America was to be found, partly in the quality of the iron, and partly in the manufacture. Mr. Gunn, Assoc. Inst. C.E., had laid on the table some specimens of American pig iron, the analysis of which showed its high quality.[1] One example was a

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[1] The following analyses of American pig iron have been kindly communicated by Mr. Gunn, Assoc. Inst. C.E.:—

For Bessemer Steel.

Smelted with coke and bituminous coal.

Amity brand.—Sulphur.		minute trace.
	Phosphorus	0·154
	Silicon	3·485

Smelted with charcoal, and with blast at 700°.

Moose Lake.—Sulphur		0·005
	Carbon	0·000
	Phosphorus	0·116
	Silicon	1·329

Smelted with charcoal.

Raccoon.—Sulphur		0·017
	Phosphorus	0·012
	Silicon	2·624

For Crucible Steel.

A cold-blast charcoal iron.

Relay.—Sulphur		trace.
	Carbon	0·283
	Phosphorus	0·027
	Silicon	0·014
	Slag	0·264
	Iron	99·412

Warm-blast charcoal irons.

Rondale.—Sulphur	0·007	to 0·019
Phosphorus	1·08	„ 1·20
Silicon	1·12	„ 1·33
Raleigh.—Sulphur	0·004	„ 0·014
Phosphorus	0·07	„ 0·07
Silicon	1·06	„ 0·93

Eagle, Longswamp, Black Lake, are all cold-blast charcoal irons of extraordinary strength, made from superior ores, which ores are first roasted and then smelted. A stalwart man using a heavy sledge-hammer will often grow weary when trying to break a pig of either of these irons. Two strong men have been seen to take turns in hammering, and finally to give up in despair. For locomotive boiler plates, chilled rolls, and any purpose where great strength is needed, these irons are very valuable.

Salisbury is known widely as a cold-blast charcoal iron of high character. Iron can be furnished which has a tensile strength in the pig of from 28,000 to 35,000 lbs. to the square inch.

piece of a car wheel which had run 70,000 miles, and which, even then, showed a tensile strength of 33,000 lbs. per square inch. Mr. Starbuck, of Birkenhead, who had a large experience in tramway cars, said he could never get English cast iron to stand, and that he therefore used American wheels. Two or three processes of annealing were adopted. In one of these, introduced by Giesse in 1859, the wheels were removed, whilst hot, from the mould, and so piled up in a cylindrical chamber, that the 'hubs' or naves formed a chimney, through which a blast of air, which could be regulated by dampers, was passed, thus gradually cooling the wheels from the centre and preventing the naves from shrinking away from the rims, as might otherwise be the case. In another process, adopted by Mowry in 1861, the wheels were built up in a pit having double walls, with layers of charcoal between them, and were exposed to moderate but protracted heat, and then allowed to cool very gradually. In both these processes care was needed to prevent the heat being such as to draw the chill, which had been imparted in the mould, to the treads and flanges, and which penetrated to a depth of from $\frac{3}{8}$ to $\frac{1}{2}$ inch. To avoid this difficulty a modification, by Moore in 1865, removed the wheels from the moulds while hot and placed them above one another in a chamber, with rings between the tires so as to shut off the chilled portion of the tire from the inner part of the wheel; the naves were then immersed in charcoal, and the tires in sand. The charcoal slowly burned, gradually annealing the bosses of the wheels, while the sand prevented the chill from being injured. In the case of cast-iron driving wheels, dry steam was passed through them while they were lying in the mould itself. He would direct attention to some experiments recorded in the "Engineer" for November 6th, 1874, showing the remarkable strength of American cast-iron wheels. One wheel 2 feet 7 inches in diameter, when subjected to a pressure applied to the rim in direct line with the nave, with a bearing upon the rim of $5\frac{1}{2}$ inches, required 110 tons to break it. Another was first forced by a pressure of 134 tons on to an axle $\frac{1}{16}$ larger than the hole in the nave, was then taken off, and bore a pressure of 178 tons, applied to the rim, as in the former case, without fracture. One reason for using cast-iron wheels in one place and steel tires in another was that the Americans did not generally elevate the outer rail on curves, so that the leading wheel of a bogie truck had a great deal to do; besides, the work of guiding was thrown entirely upon the bogie truck. The consequence was that steel tires being soft, wore thin, and became dangerous, whilst in cast-iron wheels the chill was so hard

that they could not be turned; by which also the expense of turning-up was saved. A cast-iron wheel was also safer in cold weather than a wrought-iron tire, being homogeneous and less liable to snap. On the St. Petersburg and Moscow railway, and on Canadian lines, cast-iron wheels had stood a temperature 40° below zero, in which wrought iron or steel would be liable to break. Such wheels were very durable, having a life of 100,000 miles, no authority putting it less than 75,000 miles. With driving wheels the case was different. The diameter was large; the surface of the tread must be soft and true; and when it became untrue, it must be capable of being turned up again. At the date of Mr. Colburn's Paper chilled tires were in use, but they were now generally abandoned, except for shunting engines, where the driving wheel had to do some of the guiding. In that case, the tire was fastened by a slight coning of the rim to the extent of $\frac{1}{4}$ inch in $5\frac{1}{2}$ inches and by rim bolts.

The extra width of cuttings was given because of the amount of snow that collected at the bottom of the slopes. 'Shimming' consisted in raising the rail by strips of wood on the top of the sleeper, when the ground was frozen so hard that it could not be moved. The first frost upset the track; then a thaw came, and afterwards a frost again; and the road got into such a lamentable condition, that, but for shimming, nothing could be done with it during the winter. If the shim was thick it was placed upon the sleeper, and two spikes were driven through to secure it to the sleeper, and separate spikes to secure the rail to the shim itself. Shims were sometimes employed to take 'slacks' out of the road when it was not frozen. With reference to the weight of rails, allusion had been made to difficulties which had arisen on the Ilfracombe railway. He considered the fault lay, not with the rail, but with the engine. Had a bogie truck been used, the rigid wheel base been reduced, and the weights adjusted, the rail would not have been damaged. He had adopted much lighter rails, weighing only 40 lbs. to the yard, in Canada, where the frosts were severe, and in Australia, and elsewhere, in connection with sharp curves and steep gradients, and they answered well even for heavy traffic, where the speeds were slow, and the rolling loads did not exceed $3\frac{1}{2}$ tons per wheel. Dr. Pole had asked a question as to fang-bolts. Formerly the general practice in Canada was to have an insistent joint for fastening the rails; but he considered that insufficient, and therefore arranged for a fang-bolt with an extra length of thread, so that shims could be used to some extent; but, although loosely fitted, the fang-nut soon rusted

up hard and fast, and it had to be abandoned. The chief engineer of the Toronto, Grey, and Bruce railway, Mr. Wragge, M. Inst. C.E., had now reverted to suspended joints, and only dog-spikes were used. In this country wood screws were not only expensive, but liable to be converted, by being driven instead of screwed into the sleeper, into inferior spikes. If screws were to be used at all, it would be well to adopt the American three-threaded screw, which was intended to be driven, turning round in penetrating the timber. Such screws were largely used in the United States for packing cases. Some surprise had been expressed at the short time occupied in the change of gauge mentioned in the Paper. His brother, Mr. Francis Fox, M. Inst. C.E., was in America when it occurred, and the statement was taken from official records. A similar operation was carried out on the Grand Trunk railway in October last. At ten o'clock in the morning of the 26th a length of 552 miles, or including sidings, 600 miles of railway was cleared of traffic; and by one o'clock on the following morning the gauge was completely changed. Two thousand men were employed. In Captain Tyler's report on the Erie railway some interesting statistics were given on this subject.[1] In conclusion, he hoped this discussion might aid in awakening increased interest in the public works of the United States, and that English engineers would be led to visit in greater numbers a country where they would find their professional brethren not only most courteous, but able and enterprising in the highest degree.

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[1] *Vide* "Report on the Erie Railway, and its Connections," p. 27. Folio. London, 1874.

December 1, 1874.
THOS. E. HARRISON, President,
in the Chair.

And

December 8, 1874.
JOHN FREDERIC BATEMAN, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,332, on "The Pennsylvania Railroad; with remarks on American Railway Construction and Management," by Messrs. Charles Douglas Fox and Francis Fox, occupied the whole of these evenings.

The following candidates were balloted for and duly elected on the 1st of December:—Robert Dundas, Robert Gordon, Francis Baker Hanna, Alfred Reid Clanny Harrison, Peter Alexander Peterson, William Henry Thomas, and John Brown Young, as Members; Henry Charles Baggallay, Stud. Inst. C.E., Donald Barlow Bain, Charles Spruyt de Bay, Donald Stuart Baynes, Lieut. James Brebner, Francis Eustace Burke, Stud. Inst. C.E., John Clark, George Fitz-roy Cole, Alfred Davis, Edward Baudouin Ellice-Clark, George Estall, George Lancelot Eyles, Charles Richard Fenwick, Stud. Inst. C.E., George Findlay, William Gilchrist Gilchrist, Stud. Inst. C.E., Harry Daniel Good, John Duncan Grant, William Cecil Gunn, Edmund Legh Harris, Henry Beecroft Harvey, William Harvey, Lieut. Henry Sidney Freeman Haynes, R.E., William Marshall Hewat, John Hewson, William Edward Horn, Stud. Inst. C.E., Fletcher James Ivens, Stud. Inst. C.E., George John Manders, William Holt Martin, Kenneth William Alister Grant McAlpin, David Edward McDonald, Vitale Domenico de Michele, Lieut. John Francis James Miller, B.S.C., Muncherjee Cawasjee Murzban, William Ensor Parry, Thomas Peacock, Alfred Phillips, Alfred Coveney Priestley, John Rawlins, Frederick Ewart Robertson, Frederick Smith, Harrison Veevers, and Samuel John Wilde, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 7, of the Bye-Laws, had transferred Thomas Edward Dunn, David Marr Henderson, Gabriel James Morrison, Middleton Rayne, Henry Sadleir Ridings, B.A., and William Ridley, from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :—John Baker, William Townshend Batten, Arthur Wilbraham Dillon Bell, Henry Taylor Bovey, Herbert Dorning, Charles William Freke Farewell, Henry Edmunds Haddon, Henry Thomas Hall, William Harker, Matthew Wilson Hervey, Henry Burdon Hutchings, Alfred John Ingram, George Arthur Jones, Robert Patrick Tredennick Logan, Walter Lucas Lynde, John Charles Mackay, Robert Valentine Milne, Carl Ernest Moline, Arthur Spence Moss, Alfred Thomas Mullaly, Henry Peacey, Alexander Davidson Stevenson, Harry Tee, Joseph John Tylor, William Barton Worthington, B. Sc., and Julius Dent Young.

December 15, 1874.

THOS. E. HARRISON, President,
in the Chair.

No. 1,389.—"The New South Breakwater at Aberdeen."[1] By William Dyce Cay, M. Inst. C.E.

The New South Breakwater forms part of the scheme now being carried out by the Aberdeen Harbour Commissioners, under the Act of 1868, and was completed in the autumn of 1873. The breakwater shelters the entrance of the harbour from seas raised by south-easterly gales; and, combined with the proposed extension of the North Pier, it will carry the mouth of the harbour seaward into deeper water and increase its width.

In the original design, a solid wall of Portland-cement concrete blocks was to have been founded on a bed excavated in the bottom of the sea. Liquid concrete hearting was to have been introduced into the upper portion of the work, and an apron of concrete blocks was intended to have been laid along the toe of the breakwater, where necessary, to protect the foundation.

In carrying out the works various methods for building with concrete in a liquid condition, deposited *in situ*, were tried. The results proving satisfactory, the original design was, to some extent, departed from, and the deep-water portion was composed instead as follows: The foundation, after the loose material had been removed, was constructed of large bags of liquid concrete. On this foundation the work was raised, with concrete blocks of from 9 tons to 24 tons each, to 1 foot above low water of ordinary neap tides; from this level to the roadway, a height of 18 feet, the structure was entirely of liquid concrete deposited *in situ*. The toe of the work was protected by an apron formed of a row of bags, each bag containing about 100 tons of concrete.

Concrete Foundations.

For the first 500 feet from the shore the foundation rests on granite rock; then for about 100 feet on boulders and gravel;

[1] The discussion on this Paper was taken in conjunction with the succeeding one.

and for the remainder of the distance on clay mixed with gravel, covered with large stones.

Bags of concrete were adopted for the foundations, in the first instance, on account of the difficulty of levelling the granite rock below low water. They were continued for the remainder of the breakwater, as the results proved successful, and the ground was sufficiently solid to admit of their use, when protected by an apron. The bags were deposited by iron skips or boxes, the greater part by two skips, each holding $5\frac{1}{4}$ tons of concrete, their inside dimensions being 6 feet by 4 feet by $3\frac{1}{2}$ feet deep (Plate 8, Figs. 11, 12, and 13). In the last year a skip of 16 tons capacity was used, its dimensions inside being 9 feet by 6 feet by 6 feet (Figs. 8, 9, and 10). The bottoms of the skips open on hinges, the hook which holds them being released by a trigger. In the larger skip the closing of the doors, after the bag is deposited, is assisted by counterbalance weights. The bag, of the same shape as the skip but rather larger, is fitted into it and temporarily lashed at the top, so that it lines the skip. It is then filled with liquid concrete, the temporary lashings are removed, and the mouth of the bag is sewn up. The skip, with its contents, is lowered by a crane to the divers, and moved about, in obedience to their signals, until close over the required position, when the trigger is pulled by a rope from above, which releases the bottom of the skip and discharges the bag.

The foundations were rapidly laid in this manner, the ground being cleared, in advance, of loose stones and sand, by divers; while the divers working the skips gave information as to the necessary depth of bags to bring the foundation up to the proper level, making allowance for the flattening-out of the bag when deposited. If the bag stood too high it was beaten with heavy rammers while fresh; or, when partially set, the top of the bag was removed and the concrete was cut down to the required level. Small holes in the surface were filled with bags deposited by hand. The proportions of the concrete most suitable for this kind of work are 1 of cement to $2\frac{1}{2}$ of sand and $3\frac{1}{2}$ of gravel.

Sea Staging (Plate 9).

This consisted of solid timber framework, supported on Oregon pine masts (Figs. 14, 15, and 16), its upper surface being 30 feet above H. W. O. S. T. The masts rested on cast-iron shoes or sole-plates, with sockets on the upper side for their reception; the shoes weighed $11\frac{1}{2}$ cwt. each, and the soles were octagonal, 3 feet 8 inches across. When the bottom was of rock, a pin,

2 inches in diameter, with a collar about 6 inches from its lower extremity, was inserted as far as the under side of the collar into the end of the mast, which was then hooped, and a hole drilled in the rock received the pin when the mast was erected. The masts were 21 inches in diameter at a third from the butt, and their finished length when in the staging of the outer part of the work was 65 feet. Sixty-eight Oregon masts were used; their average cost delivered at Aberdeen was about £39 each, or £9 per load.

Dantzic masts were used for the shorter supports, twenty-four in number, at the shore end; their diameter was 21 inches at a fourth from the butt; they cost £30 10*s.* each, or £6 17*s.* 6*d.* per load delivered at Aberdeen. The smaller end of the mast rested on the shoe before described; the butt was dressed to a cylindrical form for a height of upwards of 4 feet, and was surmounted by a cast-iron cap weighing 32 cwt. The lower side of the cap had a cast-iron socket, 4 feet deep, into which the cylindrical head of the mast fitted. The upper side was a flat table, measuring 6 feet 10½ inches in the longitudinal direction of the staging, and 6 feet 2 inches in the transverse direction; the top framework of the staging was bolted to this table, small flanges being cast at the sides of the bed of the beams to give their fastening additional security.

The masts were in pairs, 27 feet apart from centre to centre in the transverse direction, each pair being 18 feet 1 inch distant from the next in the longitudinal direction of the staging. The superstructure was a framework of beams of pitch pine, bolted to the top of the cap, and composed as follows: Two longitudinal girders, one on each side of the staging, rested on the iron caps above the centres of the masts; each girder consisted of three pieces of pitch pine, of 13 inches by 13 inches scantling, placed one on the top of the other, with timber keys, 3 inches by 4 inches wide, sunk in between each beam about 3 feet 4 inches apart. Wrought-iron bolts, 1 inch and 1¼ inch in diameter, passing through the beams, made the whole into a girder 13 inches by 3 feet 2 inches deep. A rail weighing 56 lbs. to the yard, on which the cranes travelled, was placed on the top of each longitudinal girder above a packing piece, 9 inches wide by 4 inches thick, covering the bolt heads. The girders were in lengths of 36 feet 2 inches, each length thus passing over two bays of the staging. The end of the girder at one side was 18 feet 1 inch in advance of the end of the other girder, so that the joints broke bond, and there was only one joint on each transverse pair of piles. The end joints butted against one another above the centre of a mast, and were spliced by covering pieces of

timber, 7 feet by 13 inches by 6½ inches, there being six pieces to each joint, and bolts.

The transverse girders, one of which connected the two masts of a pair, consisted each of three pitch-pine beams, 14 inches by 14 inches, which, when keyed and bolted together, formed a girder 14 inches broad by 3 feet 6 inches deep. They were fastened to the iron caps, their bed being at the same level as the bed of the longitudinal girders, and were secured to the longitudinal girders, against which they butted, by both of them being bolted to short logs placed vertically in the corners. For additional security the staging was braced in the following manner: A horizontal wrought-iron strut, composed of a central bar 3 inches in diameter, trussed by four outer rods 1 inch in diameter, was placed between the two masts of each pair in the transverse direction about the level of half tide, and diagonal tie-rods 1½ inch in diameter extended from the ends to the opposite caps. Wrought-iron anchors, of about 18 cwt. each, were laid outside the staging, with the top of which they were connected by chains at about every third pair of masts; the chains were long rods 1½ inch in diameter, with eyes at their ends, shackled together. The top framework was further braced by two horizontal transverse tie-rods, 1½ inch in diameter, at each transverse beam; diagonal horizontal tie-rods were also inserted between the opposite ends of each adjoining pair of transverse beams in those bays of the staging not in use for building, or in winter to provide additional stiffness. To erect the staging, a hole was excavated by the divers, about 2 feet deep, for the reception of the shoe which was set by them. The mast, having previously been dressed on shore to fit the shoe and the cap, was floated out and heaved into a vertical position by the steam derrick crane at the extremity of the staging; its lower end being guided into the socket of the shoe by the divers, and its upper end secured between spars temporarily fixed to, and projecting from, the staging already erected; the cap and the upper framework of the staging were then put on, and the tie-rods and bolts fixed. In this manner the staging could be erected at the rate of one mast, equivalent to an advance of 9 feet lineal of staging, in two days; the largest amount of work reported was 108 lineal feet of staging in four weeks. As the width of the breakwater was 35 feet at the level of the roadway, and the staging 27 feet between the centres of the masts, while the centre lines of the breakwater and of the staging coincided, the masts were all within the line of the work and were built into it. This was a great security to the staging; only as much of it being needed in advance as was necessary to carry on the building.

Generally in summer ten pairs of masts were in advance; while in the late autumn their erection was retarded or stopped, so that on finishing work for the season not more than three or four pairs of masts were left standing in the sea, and one or two of these were built in at their feet by the lower courses of the breakwater.

Only 360 lineal feet of the upper framework of the staging, including the iron caps, was provided, that in the rear being taken down and used again in the front. The heads of the masts were sawn off at the level of the roadway, after the superstructure was removed. A short piece of staging, consisting of logs and posts of pitch-pine, was erected on shore, at the same level as the top of the sea staging, to receive the cranes in winter or during stormy weather; and the cranes were conveyed from the sea to the shore staging on a carriage running on rails on the breakwater, the rails on the top of the carriage being at the same level as the rails on the staging. The crane carriage had eight travelling wheels, each of them actuated by double-purchase travelling gearing worked by hand. The carriage weighed 33 tons, and the crane, with its crab, 70 tons more, being a total of 103 tons. This weight was easily moved in and out, each operation taking about one hour. The solidity of the staging and its height and weight gave confidence in its power to resist violent storms. The only risk was from its being run into by ships, but this was to some extent obviated by the exhibition of lights at the end. No accident happened either from ships or from the violence of the sea.

Sea-staging Cranes (Plate 9).

There were two 25-ton steam goliath travelling cranes on the sea staging, with crab-ways overhanging on each side, thus giving a total transverse travel of the centre of the load of 42 feet. The 25-ton steam crabs were made by Messrs. Stothert and Pitt, of Bath, and each cost, with chains, blocks, lying shaft, and sprocket wheels and chains for working the travelling gear of the gantry, £500 delivered at Aberdeen. The gantry was of pitch pine. Each crab-way consisted of pieces 15 inches by 15 inches, keyed and bolted together, so as to form a girder 55 feet long by 15 inches wide by 3 feet 9 inches deep. Each crane had ten travelling wheels, and the entire cost, with the crab erected ready for work, was about £1,340. A 3-ton steam derrick crane, with a 50-feet jib, made by Messrs. Butters Brothers, Glasgow, was employed for erecting the staging at the end. The cost of this crane was £170 delivered at Aberdeen. It was erected on a carriage

with hand travelling gear, costing £100; the gauge of the wheels was 27 feet, the same as that of the 25-ton cranes, there being only two rails on the top of the staging.

Concrete-building in Frames (Plate 8).

For a length of 363 feet, extending to low water of spring tides and the outer edges of the rocky foreshore, the breakwater was built of liquid concrete deposited *in situ*, in frames or cases (Figs. 1–7). The upper 18 feet of the remainder of the breakwater, extending vertically from the level of 1 foot above low water of neap tides to the roadway of the breakwater, was also constructed in like manner.

A framework of posts was erected round the site of the building, excepting at the end of the completed work, which formed one side of the case. The posts were provided with grooves, into which panels were slid, extending from post to post. The bottom and sides of the case were lined with jute bagging, and tie-rods, passing through the posts and from side to side, prevented the case from being burst open by the lateral pressure of the liquid concrete. The heart of each post was a piece of Baltic fir, 20 feet long by 12 inches by 6 inches scantling; the pieces of wood forming the grooves were fixed to the larger sides, the outer pieces being bolted through the heart piece, and the inner ones being spiked. The panels were built up of short pieces of plank, 2 feet long, placed vertically alongside one another, so as to form a slab about 7 feet 9 inches by 2 feet by 3 inches; and they were backed by two planks, placed horizontally, about 7 feet 4 inches by 11 inches by 3 inches each; the ends of the latter formed the tongues which slid in the grooves in the sides of the posts. The tie-rods were of wrought iron, $\frac{3}{4}$ inch diameter, in convenient lengths, connected by $\frac{3}{4}$-inch shackles; the end of the tie-rod passing through the post was a bolt 1 inch diameter, to which washers and a nut were fastened outside the post. The jute bagging was 39 inches wide, and weighed 29½ oz.; it cost 8*d.* per lineal yard, and could generally be used twice. The framework was made of small pieces, easily portable by a few men, to admit of the execution of the first 300 feet of the breakwater, as there was no crane commanding the work, the staging not being then erected. Where crane power is available, the framework might be as quickly erected in large sections previously made up on shore. In this way the small outlay for tie-rods passing through the work, and built in and lost, might be partly avoided.

In executing the concrete-building *in situ* above low-water level, it was considered important to exclude the tide from the unset concrete. To effect this the cases were arranged of such size that, by commencing when the tide left the foundation of the piece, the concrete could be filled in and raised in the case faster than the tide rose, so that its surface was always above the level of the sea outside. The sides of the mass, when filled in, were sufficiently protected from the wash of the waves by the framework lined with jute bagging; and the weight and setting properties of the concrete preserved it from damage by the percolation of water. In this way the concrete was put in without being damaged by the sea water, and it set as perfectly as on shore, becoming, in fact, harder than the blocks made in the block-yard, owing to its surface being kept constantly damp, and there being no loss of the moisture necessary for the perfect setting of the cement. Each piece extended completely across the breakwater, and was thus 37¼ feet wide, the breakwater being 35 feet wide at the top, with a batter on each side of 1 in 8. The pieces were 18 feet deep; their length varied from 8 feet to 31 feet, so that the weight of each ranged from 335 tons to 1,300 tons. The following is a list of the pieces executed in 1872 and 1873:—

In the Year ending Sept. 30th, 1872.		In the Year ending Sept. 30th, 1873.	
Lengths.	Weights.	Lengths.	Weights.
Feet.	Tons.	Feet.	Tons.
16¼	680	20	838
16	670	18	754
8	335	16	670
16	670	20	838
17	712	23	964
16	670	30	1,257
17	712	24	1,006
20	838	31	1,299
17	712	24	1,006
17	712	30½	1,278
20	838	21	1,090
19	796	16	830
19	796	27	1,169
16	670		
19	796		
17	712		
20	838		
16	670		

The great size of the pieces in 1873 was rendered possible by incorporating a number of concrete blocks with the liquid concrete, to the extent sometimes of one-fifth of the whole mass; the

machinery not being sufficient to produce liquid concrete to fill up so large a piece to high-water level in one tide. The use of large pieces saved time as compared with small ones, as the diving work was to some extent hindered while the concrete was being filled in.

When the frame at the outer end of the piece was removed, and another piece added, a vertical joint was left between them. The pieces did not adhere to one another at this joint; and when the roadway of the breakwater was washed clean by a storm, a fine crack marked the position of the joint. These cracks remained open for a year or so after the concrete was deposited, owing probably to a minute settlement of the work. The Author is of opinion that pieces about 16 feet long and 670 tons weight were the best for this work, as in case of a slight settlement of the foundations, short pieces would settle with it and maintain the security afforded by their weight on the courses of blocks below them; while a longer piece, of say 30 feet, would be apt to bridge over a settlement, and not bear on the blocks, which without the pressure of its weight are liable to be shaken and shattered by the sea. In the case of a small piece of the foundation having been accidentally undermined by the divers about the close of a building season, eight of the blocks in the upper course lying below the liquid concrete at low-water level were cracked by the sea, and had to be picked out as far as their hardness would permit, and built in again solidly.

The panels at the end of the frame were planks 6 feet 6 inches long by 11 inches by 3 inches, so that half of each post was buried in the concrete, forming when taken out vertical grooves from the top to the bottom of the piece. The concrete of the next piece fitted into the grooves, and prevented lateral movement of one without the adjoining piece. Thus the concrete top formed a mass practically monolithic in the horizontal direction, while in the vertical direction each piece had an advantageous power of settlement or adjustment.

The expense of the framework was trifling, as the posts and panels were used until worn out. That of the iron tie-rods was about 6*d.* per cubic yard of concrete, and of the jute bagging about 2*d.* It will be seen from the statement of the expenditure, at the end of the Paper, that the concrete built *in situ* was cheaper than the blocks manufactured and stored in the yard, without including the additional expense required for setting the latter in the work.

These masses of concrete gave great security in the progress of

the work. Their construction was kept well up with the advance of the foundations; and as soon as a length of the work had received its covering of concrete, it was safe from the effect of storms. The framework was seldom injured by the sea; a piece was considered practically secure if it had been in twenty-four hours before the storm began. In the few cases of the framework being partially swept off by the sea while the concrete was new, the damage was slight, as the destruction did not progress so fast as the hardening of the concrete and its power to resist the sea. The proportions of the concrete found best for this work, keeping in view the risks from storms when new, were 1 of cement to 3 of sand and 4 of gravel. Much of the work was, however, done in the middle of the fine season with concrete of the ordinary proportions for blocks, viz., 1 of cement to 4 of sand and 5 of gravel.

Concrete Apron (Plate 10).

An apron of concrete was placed along the sea or east side of the foundations. Commencing where the rock ceased, at about 500 feet from the shore, it was carried round the head of the breakwater and returned along the harbour side for 110 feet. On the east side the apron was of a substantial character, constructed of a row of fifteen bags of concrete, each bag containing about 100 tons, to avoid risk of damage from undermining by the sea, which would have injured the work in a manner difficult to repair.

The machinery for this was a box of pitch pine, capable of holding 100 tons of concrete, supported at its ends on two brackets projecting from the breakwater over the site on which the bag was to be deposited (Figs. 17, 18, and 19). The bag, which was a little larger than the inside of the box, was then fitted into it, and filled with liquid concrete; when full, the mouth or cloth lid of the bag was sewn up, and the bottom of the box, which turned on two wrought-iron hinges on one side, was opened by pulling two triggers holding up the other. In this way the bag of concrete was dropped into the site excavated for it, close to the toe of the foundation of the breakwater. In shape the box was rectangular, but slightly larger at the bottom than at the top, to allow of the bag leaving it easily. Its average dimensions inside were 32 feet 1 inch by 8 feet 1 inch by 6 feet deep; the sides consisted of top and bottom pieces, 15 inches by 15 inches, and between them were two pieces 13 inches by 13 inches, and one piece 13 inches by 16 inches. Wooden keys, 3 inches by 4 inches, were fitted transversely between each piece, and the whole bolted together so as to

form a timber girder 6 feet deep, by 15 inches wide at the top and bottom and 13 inches wide in the middle.

The bottom was a strong timber framework, consisting of two solid timber girders along each side, 4 feet 8 inches deep, braced together with diagonals and bolts, and with 4-inch planking laid transversely on the top. The weight of the straps and pins of the two wrought-iron hinges was 42 cwt., the pins being 4 inches in diameter. The triggers supporting the bottom at the opposite side from the hinges were perpendicular to the side of the box. The part of the trigger next the box was a hook formed of one $\frac{1}{2}$-inch and four $\frac{3}{4}$-inch boiler plates riveted together; the hook hung from a hinge pin, $3\frac{1}{2}$ inches in diameter, suspended by wrought-iron straps bolted to the side of the box. The flattened point of the hook caught and supported the bottom, the upper beam of which, armed with a wrought-iron washer plate, rested on the point. When in this position the point of the hook was vertically under the axis of its hinge pin. The back of the hook was prolonged into a triangular arm of boiler-plate web with top and bottom angle irons, having an eye at the end: a chain, fixed in the eye, when heaved up disengaged the point of the hooked part of the trigger from the bottom of the box, and the bottom then fell open. The triggers measured 3 feet $1\frac{1}{2}$ inch from the centre of the hinge pin to the bottom of the hook, and 8 feet 8 inches from the same point to the end of the arm, and the weight of each trigger was 13 cwt. One trigger would have been better than two, as there was a difficulty in discharging them simultaneously; but this would have necessitated a box with a much stronger bottom. In working with the 100-ton hopper box the following precautions were taken to avoid damage from storms: Brackets were fixed to the top of the staging, or 30 feet above H. W. O. S. T. On these the box was lashed immediately after the work was done. The bottom and triggers were unhinged and removed, and the working brackets were also taken away. At the close of the season the sides of the box were likewise removed to the block-yard. The weight of the sides of the box was 17 tons, that of the bottom 17 tons, but the whole was easily moved by the two 25-ton staging cranes, one holding up each end. Two or three bags were generally deposited in succession, and the work was carried on night and day till finished, when the box and brackets were cleared away and secured as described. On one occasion three 100-ton bags were deposited in forty-seven hours, reckoning from the time the bottom of the box was taken out to the work to the time it was brought back to the shore. Before the workmen were practised in

the use of the box some of the bags were dropped 2 or 3 feet short of the toe of the work. In this case the intervening channel was filled with small bags of concrete of 5 tons weight, deposited by a skip. The large box was filled by the aid of smaller ones of wood, holding about 6 tons each, which were loaded under the mixers, carried down to the box, and lifted into it by the cranes.

Head of Breakwater (Plate 10).

The extremity of the breakwater was finished with a semicircular end, the diameter of the semicircle being the width of the breakwater, so that there was no projection on either side. The foundations were protected beyond the end by a triple row of 16-ton bags of concrete, which were continued round the harbour side for 110 feet, the 100-ton bags protecting the sea side. For security, the concrete blocks were dovetailed into one another, and the concrete cap was carried 4 feet lower than usual, or 22 feet below the roadway. Above this was placed a tower, 20 feet high (Figs. 22 and 23), of liquid concrete built *in sitû*, of 1,040 tons, so as to add weight to it; and the tower is surmounted by a concrete lighthouse 62½ feet high.

Diving.

The diving work was all executed with helmet apparatus supplied by Messrs. Siebe and Gorman, of London. There were six sets of the double apparatus, in which each air-pump supplied two divers, and two sets of single apparatus. In general twelve divers were under water simultaneously out of six boats.

A copy of the following regulations was hung up in the divers' hut:—

"I. Four hours to be a tide, provided it is occupied as under.

"II. Divers to dress in own time, and to be at ferry-boat landing on breakwater 10 minutes before the time appointed for commencing tide.

"III. Divers will be allowed an interval of 15 minutes during a tide, and 15 minutes at end of tide for undressing, making the working time 3½ hours.

"IV. Commencement of a tide to be reckoned from the time the helmet is put on."

In the summer season four shifts of diving work were obtained in a day, the first shift going down at 4 A.M., and the last shift coming up at 8 P.M. The principal divers worked two shifts per day and one on Saturday, being eleven shifts per week, the pay for which was 66*s*. They had no standing pay; but received diving pay when diving, and when working out of the water the ordinary pay per hour

given to other workmen of the trade to which they belonged. There were thirty-two divers, thirty of whom were trained on the work, and two came from other places. The occupation was popular among the men, and they were anxious to work two shifts per day. The Author was informed that they enjoyed excellent health. One man lost some weight in the course of the season. Beginners were occasionally sick after being down, but they soon got over the tendency.

The best boats for this work were carvel built, 25 feet long by 8 feet 9 inches broad, and 3 feet 9 inches deep. Two of them were built on the work, and five were supplied by contract, at an average cost, delivered complete, of £35. During work the divers were generally arranged as follows:—Four excavated for and set the shoes of the staging masts, four cleared the loose stones and material from the site of the work, and four were engaged in excavating the foundations and arranging the bags and blocks.

Concrete Blocks.

From the bag-work in the foundations up to 1 foot above low water of neap tides, where building in liquid concrete *in situ* commenced, the work was composed of concrete blocks manufactured in the block-yard. These blocks were all 4 feet high, and usually 6 feet wide. At first they were of sizes varying in weight from 7½ to 18 tons; latterly the small blocks were mostly used for incorporating among the liquid concrete, and the larger, from 10½ to 24 tons weight, for block building. The blocks for the head of the breakwater were radiated and dovetailed into each other, a semi-cylindrical projection cast on one fitting into a corresponding recess in the next. The weight of some of these blocks was 25 tons. The blocks were cast in wooden moulds in the usual manner, and stacked by cranes in the block-yard to harden. They were then taken down the incline on wagons to the staging cranes, by which they were lowered to, and set by, the divers.

The block-yard cranes were a 25-ton steam goliath, a 15-ton hand goliath, and a 20-ton hand over-head traveller on staging. The steam crane was best for handling heavy weights; and the economy in working it more than paid for the additional first cost of the steam power.

The proportions of the concrete in the blocks were 1 of cement to 4 of sand and 5 of gravel; large rough pieces of broken stone were also incorporated. The most approved method of making the blocks was to lay a timber platform alongside the single line of rails through the yard under each crane, and on this to set the

moulds. The concrete was shovelled into the moulds from ordinary earth wagons, which, when emptied, were drawn out at the opposite end of the yard. In this way the wagons circulated without interfering with one another, and the men were well dispersed over the work. About three thousand blocks were constructed.

Concrete-making.

The concrete mixers of Mr. P. J. Messent, M. Inst. C.E., were employed. Four of them, to mix about ½ cubic yard each at a time, were arranged in a row and driven by an 8-HP. steam-engine. The wagons, to receive the concrete, ran in below the mixers, which were filled by hoppers from a platform above; this measuring platform communicated by an embankment at the same level with the places from which the materials were brought. Each mixer turned out 12 cubic yards of concrete per hour, or 48 cubic yards for the four, when worked at full speed. They were driven at the rate of about eighteen revolutions per minute; and twenty to twenty-four revolutions sufficed to mix the concrete thoroughly.

The gravel was mostly granite, mainly from the beach at the bay of Nigg, about ¾ mile from the mixers, to which it was brought on a tramway. Excellent sharp, clean sand was obtained at the back of the works, from a quarry excavated in the hill, at the level of the mixers, with a working face of about 50 feet high. The upper stratum of 12 to 18 feet consisted of terr of an unsuitable quality. The quarry-face was about 300 yards from the mixers. Fresh water was obtained from a spring on the shore, where it was collected in a pond and pumped to the top of the hill at the back of the work, whence it supplied the mixers and the steam cranes in the yard and on the sea staging, by gravitation.

Cement.

Portland cement was used for the concrete; the following is the description of it in the last specification issued:—

"It is to be finely ground, and when sifted through a gauze sieve having 900 holes to the square inch, at least 95 per cent. by weight of the cement is to pass through without rubbing. It is to weigh not less than 115 lbs. per striked bushel, imperial measure, filled from a spout or hopper 18 inches above the mouth of the bushel. Sample blocks are to be made of the cement in a metal mould having a minimum area of 2¼ square inches; these blocks are to be immersed in water immediately after setting sufficiently to allow of their being taken out of the mould, and are to remain

in the water until tested; at the expiry of seven days after gauging they are to be tested by tensile strain, and are to bear without breaking a strain of 600 lbs. per block. The cement at the time of delivery is to be in all respects ready for use, and there are to be no cracks, or symptoms of 'blowing' or heat in the sample blocks."

The price, delivered alongside Torry pier in Aberdeen Harbour, about $\frac{3}{4}$ mile from the works, exclusive of harbour dues, averaged 39*s.* 3*d.* per ton. When stored on the works it cost, including dues, 43*s.* per ton. About 6,220 tons were used. Fifty briquettes were made out of each cargo, immersed in water for seven days, and tested for tensile strength by a steelyard constructed by Mr. P. Adie, Assoc. Inst. C.E. The cement was delivered in sacks, holding 2 cwt. each, and shot out on the floors of well-ventilated sheds with a capacity of about 1,000 tons.

Progress and Cost.

Preparations for the work were begun in May 1869, in the erection of buildings, and the formation of the block-yard and roads, railways, &c. In the financial year ending September 1870, the manufacture of concrete blocks was begun, and the shore end of the breakwater carried out 312 feet by concrete building *in situ*, containing 6,760 cubic yards.

In the year 1871, the staging cranes were built, part of the sea staging was erected, and the breakwater was advanced 137 feet, containing 6,135 cubic yards of building.

This year's advance was represented by—

	Cubic yards.
Concrete deposited liquid in bags in the foundations . . .	572
,, ,, ,, frames above low-water level . .	4,647
,, blocks	916
Total . . .	6,135

In 1872 a length of 300½ feet, containing 17,449 cubic yards of building, was completed, the largest progress being in June, when in four weeks the breakwater was advanced 87 lineal feet, containing 4,675 cubic yards. The work done this year was—

	Cubic yards.
Concrete deposited liquid in bags in the foundations . . .	1,572
,, ,, ,, apron	58
,, ,, ,, frames above low-water level .	6,452
,, blocks (including those set amongst the liquid concrete deposited in frames)	9,367
Total . . .	17,449

In the year ending September 1873, a further length of 300½ feet, containing 19,809 cubic yards of building, was completed; the advance in four weeks in July being 84¾ lineal feet, containing 5,886 cubic yards.

The extent of work this year was—

	Cubic yards.
Concrete deposited liquid in bags in the apron	686
,, ,, ,, ,, foundations	1,058
,, ,, ,, frames above low-water level	5,497
,, blocks (including as before)	12,568
Total.	19,809

The total length of the breakwater is 1,050 feet, which is 150 feet shorter than originally intended, the proposed length having been 1,200 feet. This shortening was determined on from considerations connected with the navigation at the entrance, and the fear that the passage of vessels might be obstructed.

The materials in the work included—

	Cubic yards.
Concrete deposited liquid in bags in the foundations	3,202
,, ,, ,, apron	744
,, ,, ,, frames above low-water level	23,356
,, blocks (including as before)	22,851
Total.	50,153

The expenditure has been as follows:—

	£.	s.	d.	£.	s.	d.
Excavating foundations of breakwater	3,834	14	7			
Concrete deposited liquid in bags in the foundations	4,045	5	2			
Ditto ditto in apron, including cost of plant	1,657	18	3			
Concrete blocks and block-making	14,839	6	7			
Block-setting	3,335	13	7			
Concrete deposited liquid in frames above low-water level	18,868	0	5			
				46,580	18	7
Preparatory works				3,229	14	9
Buildings				1,727	12	11
Plant				12,925	11	8
Sea staging				10,291	19	7
Sea light				98	19	1
Sundries and materials in store				2,009	16	1
				£76,864	12	8
By receipts for cement, &c., sold				421	6	5
Total expenditure up to the 30th of September, 1873.				£76,443	6	3

The estimate, prepared by the Author, as submitted to the Public Works Loan Commissioners, was £78,842. This was for a length of 1,200 feet, but the Author is of opinion that the remaining 150 feet beyond the present length would have been executed for the value of the plant, rails, cement, buildings, masts, iron, &c., which are for the most part to be used in another of the Aberdeen Harbour works; viz., the extension of the North Pier. He thus considers the work to have been executed at about the estimated cost.

The principal persons employed under the Author in carrying out the work were, Mr. James Barron, Inspector and Superintendent of the workmen; Messrs. William Yuill, Assoc. Inst. C.E., Robert Aytoun, and George J. Clarke, Assistant Engineers.

The Harbour Commissioners, of whom the chairman was Mr. William Leslie, Lord Provost of Aberdeen, contributed in a great degree to the success of the financial results by their interest and attention. They consulted Sir John Hawkshaw, Past-President Inst. C.E., and Mr. James Abernethy, M. Inst. C.E., on four occasions, viz., as to the original design, as to whether the work should be contracted for, on the proposed sea staging, and on the proposed shortening of the length of the breakwater.

General Remarks.

In conclusion, the Author may remark, that the concrete blocks of 10 to 20 tons appeared to be the weak point in the design. Had the foundation turned out to be of sand or soft material their use must have been given up, as a slight yielding of the foundations would take off the superincumbent weight from the blocks, and they would be loosened and broken up by the heavy seas which strike the work. The blocks composing the part of a breakwater below low-water level should be from 100 to 200 tons weight each. This practice with concrete building *in sitû* above low water would, in case of a dislocation by weakness or undermining of the foundations, enable each portion independently to resist the sea. He is also of opinion that some, if not all the blocks below low-water level, might with economy and advantage be deposited in a liquid state in bags.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 8, 9, and 10 have been compiled.

No. 1,391.—"The Extension of the South Jetty at Kustendjie, Turkey."[1] By GEORGE LENTON ROFF.

THIS jetty, which had a length in 1870 (the year in which the extension was commenced) of 450 feet, was protected against severe gales, by a mole of pièrre-perdue and concrete blocks.

The design for the extension was governed by the following points. The extension was to be regarded not as a loading pier for vessels, but as a breakwater; it had to be so constructed as to avoid the necessity of lengthening the mole: and, during the progress of the work, the existing traffic accommodation and loading berths were to be interfered with as little as possible. These considerations made large concrete blocks necessary, and restricted the space upon which they could be built to the last 50 yards in length of the jetty as then existing.

The design adopted was that of concrete blocks, weighing about 30 tons each, resting upon a base of pièrre-perdue; the blocks being placed so that each forms an integral portion of the cross section of the work. They are in tiers of four blocks, lying evenly one upon the other; each leaning back upon the preceding tier at an angle of 47° 45′ with the horizon. The bottom blocks, 18 feet long, are at a depth of 16 feet below the surface of the water. All the blocks are 6 feet high and 5 feet wide. The top of the work is 11 feet above the water, and is 12 feet wide.

Three roads were laid upon that portion of the old jetty which has been mentioned as affording the only space available, the blocks being moulded upon trollies on the two outer rows. The trollies were 20 feet long. There was room for only twelve of them, six upon each road.

The timber sides of the moulding boxes were formed of $2\frac{1}{4}$-inch planks, strengthened, and were arranged that the sides could be easily adapted to the four different lengths required. The T irons for stiffening the sides, and the tie-rods for holding them together at the top, were all separately and easily removable.

A travelling platform. standing a little higher than the top of the moulding boxes, and just wide enough to fill the space between the two rows of blocks, occupied the middle road, opposite the box to be filled. Upon this platform the concrete was mixed

[1] The discussion on this Paper was taken in conjunction with the preceding one.

by hand. It was not practicable to make more than one block at a time.

Two trucks of broken stone were placed before, and one of sand and one of cement behind, the platform; the sand and stone being passed by baskets into empty cement-casks, standing upon the edge of the platform, so as to ensure the use of regular quantities. A gang of twenty-four Turks and Bulgarians could load the material into trucks and mix one boxful per day. The stone for the concrete was procured from the foundations of ancient buildings on the Company's property. These foundations consisted of small rubble limestone and Roman tiles, generally without mortar. The stone was raised and broken by contract at a cost of 2*s.* per cubic yard. Most of the sand was brought by vessels as ballast; but when a suitable supply failed for a time, it was procured from the seashore. With strong, sharp sand the proportions used for the blocks were 5½ broken stone, 2½ sand, and 1 cement. With the native sand, these quantities were altered to 5, 2, and 1.

Before any concrete was put into the box, the two lifting bolts, by means of which the blocks were to be deposited, were so fixed that the block, when lifted, would tilt over to the proper angle, and hang in the position in which it was intended to lie. The eye end was held in place by a small wooden box, which also kept it clear of cement, and the cast washer by two pieces of twine nailed to the side of the moulding box.

The lifting bolts were 2 inches in diameter, and 6 feet long. The washers and nuts were built in, so that the bolts could be unscrewed and withdrawn after the blocks were placed. The bolts were of this length to allow for re-screwing in case of damage to the thread by withdrawing; but after the first few blocks were lowered, the expediency of tapering the bolts was evident, and all forged in this way were recovered without injury or difficulty. On the morning after the day on which the block was made, the sides of the moulding box were removed, and fixed on another trolly. In this way sides for three boxes only were necessary.

When two or three days old the top of the block was roughly dressed to a straight-edge, so that the one to be placed upon it might rest fairly. The bolts were moved about a few times to make them more easily removable when lowered; and the shoulder of the bolt, at the eye, was built round with cement to prevent it bending while the block was being tilted. This cement was knocked away when the block had been lifted. The blocks were lowered when from twelve to fourteen days old.

The gantry, carrying a travelling winch, was of timber. The piles, sills, and rail-bearers were of creosoted red pine, from England; and the uprights and braces of Transylvanian white pine, the uprights being placed in pairs, unsquared, as the scantling was small. The piles were driven until, being at least 6 feet in the ground, they did not penetrate more than 2 inches under the blow of a 12-cwt. monkey falling 12 feet. The piles were 12 feet apart, and every third pile was made fast to an anchor. Four or five bays were erected at a time, and the timbers were taken down and carried forward as the work progressed.

The blocks were pulled forward as far as a traverse, at the end of that part of the old jetty upon which they were built, by a winch fixed underneath the traverse; and thence to the gantry by another winch placed upon the blocks already lowered. While the second winch was pulling the block from the traverse to the gantry, the first was employed in moving forward the remainder of the row, to make room for the empty trolly behind. Before the lowest block of each tier was deposited, stones of $\frac{1}{2}$ to 1 cubic foot were thrown over the bottom, and a diver arranged these so that the block might have as true a bed as possible. Oolitic limestone, procured from a quarry near the railway, 14 miles distant from the harbour, was employed.

After roughly levelling the stones, a rail was let down and passed along the face of the last tier, to ascertain that no stone underneath the last bottom block projected so as to prevent the next to be lowered from lying back properly in position. This done, the diver piled up the stones to an iron set-square, which he placed against the rail, the set-square being made to correspond with the lower sides of the blocks. This operation generally occupied a whole day.

The block, having meanwhile been brought over the spot on which it was to be placed, was tilted up on edge by the act of lifting, and as soon as it hung free the empty trolly was drawn from under it. The beams and rails upon which it had stood were then pulled back out of the way, the block was turned half round so that its length was transverse to the direction of the jetty, and it was lowered into position. When the sea was rough, the block was steadied by allowing it to touch, and slide down, the face of the last tier. An iron rod, having a forked end to fit the upper edge of the block, was let down to both ends of it, to ascertain that it lay level; and the diver then packed its under side as closely as possible with stones. This being done, the lifting bolts were unscrewed and withdrawn, by means of a long rod (reaching

above the surface) having at one end a clip, which was made fast to the eye of the bolt, and at the other end a ring, through which a bar was passed and turned round like a capstan. It occupied one diver two days to properly level the base, and pack the bottom block. The other three blocks which rested upon it, and with it formed a tier, could generally be lowered in one day. Each tier extended the work a distance of 7 feet.

Under the peculiar circumstances of the case, there was nothing to be gained by employing more than one diver at a time. According to the terms of a convention with the Turkish government, the work was spread over three years. Otherwise, even with the limited space available for building the blocks, it could have been completed in half the time.

At the commencement it was intended to lift the blocks by means of two lewises; but, although these were made 4 feet 6 inches long, they split the blocks as soon as the full weight came upon them. The bolts, nuts, and washers never gave any trouble, and, with the exception of the failure of the lewises, no accident or damage happened to men or material while the blocks were being deposited.

The inclination adopted for the tiers was determined from experiments with a model. It was just sufficient to bring the centre of gravity of each block above the face of the block against which it leaned, so as to prevent any tendency of the blocks to tip forward during settlement.

The most troublesome part of the work was making the concrete slope at the end of the old jetty, against which the first tier of blocks was to rest. This could only be done solidly by lowering unset concrete into a caisson. The sides of this were made of two thicknesses of planking, the outer $2\frac{1}{2}$ inches, the inner $1\frac{1}{4}$ inch thick, with a layer of tarpaulin between. The caisson was finally secured by driving piles formed of two rails riveted together, and tipping stones on their sea face to a few feet above the water level. The water was not pumped out, but the concrete was lowered in hopper-bottomed boxes.

The topping of the blocks, which brings the jetty to a level of 11 feet above water, was done in lengths of four tiers, or 28 feet. The plank casing was supported by struts fixed to walings, bolted to the gantry piles. The concrete was mixed on the spot, and thrown in. The proportions were $6\frac{1}{2}$ broken stone, $2\frac{1}{2}$ sand, 1 cement, and stones from $\frac{1}{4}$ to 1 cubic foot, equal to about 1 more, making about 10 to 1. With this mixture a cask of cement makes 1 cubic yard of concrete.

To prove the stability of the blocks themselves, without any superincumbent weight, five tiers were left untopped from September 1872 to July 1873, at the then extreme end of the work. They were exposed to heavy seas during the winter; but none of them were disturbed or moved except by ordinary settlement. The first portion of the work has now been subjected to the full force of the sea since September 1871, the second portion, since 1872, and the last length was finished in September 1873.

To secure the end of the jetty from excessive settlement, the soft bottom beneath the last seven tiers was removed to a depth of from 3 feet to 4 feet by dredging, and blocks were placed as a footing to the last three tiers. There is no enlarged head to the jetty, the end is simply rounded, and a red light is fixed on the top of a wrought-iron upright, which is built into the concrete.

	Cubic feet.		Tons.		Tons.
The bottom blocks contain	515	and weigh from	32	to	34
„ second block in each tier contains .	485	and weighs	30	„	32
„ third „ „ „ .	455	„ „	28	„	30
„ top „ „ „ .	425	„ „	26	„	28

Each length of topping weighs over 200 tons. The total length of the extension is 253 feet 6 inches.

The natural bottom is a mixture of sand and mud overlying stiff yellow clay, and the weight of concrete presses down the loose stone base. The blocks have in every case settled vertically, without disturbing the line of direction, the only effect of settlement being to open the joints of the concrete cap. The top has nowhere given way except at the joints; and the slight openings at these points can easily be filled up with cement, so soon as settlement shall entirely cease.

The original design was by Mr. Liddell. The work has been executed by the Author for the Danube and Black Sea Railway and Kustendjie Harbour Company, Limited.

The Paper is accompanied by a drawing, from which Plate 11 has been compiled.

Mr. Parkes said there could be no doubt that the application of cement concrete to marine works was one of the great features of the engineering of the present day. The methods described in the Papers appeared to have been both well devised and carried out in a practical way. He offered no opinion as to whether the plans adopted by Mr. Cay for Aberdeen were suitable to the place. The point to be considered was the limit within which such plans were applicable at other places. With regard to the concrete in bags, if the object was to make a very solid foundation, he thought it was fully attained, but at a rather heavy cost; and in cases that might appear somewhat similar to that of Aberdeen, he should not take it for granted that the system there pursued was necessarily the best. The liquid concrete deposited in bags cost about 25*s.* per cubic yard; that which was deposited above low-water level in frames cost 16*s.*; so that the sum of 9*s.* per cubic yard was due to the extra expense of the former. There was an item for excavating the foundations of the breakwater—£3,835—which, with the 9*s.* per yard for 3,202 cubic yards, or £1,441, gave a total of £5,276 for 45,000 superficial feet, or about 2*s.* 4*d.* per superficial foot. Nor was that all the cost. It appeared that the only real use of the staging was for depositing the concrete in bags. No doubt it was afterwards employed for setting blocks, and putting in concrete in the upper works; but it was by no means necessary for either the one or the other. The money spent upon the setting machines would have provided a Titan to set the blocks off the end of the work as easily, or more easily, than they were arranged from the staging; but it would have been impossible to put in the concrete bags from a Titan. The cost of the staging, therefore, must be added, because it would not have been necessary but for the particular method adopted for the foundation. That cost was upwards of £10,000, so that the total cost of the foundations exceeded £15,000, or 7*s.* per superficial foot. Mr. Parkes knew from experience that where rubble stone could be put in for a foundation, the cost of preparing it to receive the superstructure did not exceed about 1*s.* 6*d.* per superficial foot, so that 5*s.* 6*d.* might be regarded as the extra expense of the concrete foundation, and it was a question whether the additional solidity gained was an equivalent for that amount. It might be so at Aberdeen and other places, but it ought not to be taken for granted that it was so in every case. He wished to bear testimony to the ingenious way in which the work had been devised, especially the plan of putting the bag into a hopper. The bag was somewhat larger than the box, so that, on being discharged, it spread out and

accommodated itself to the bottom. With regard to the concrete blocks of from 10 to 20 tons, he agreed in the opinion that the plan was not altogether faultless. He objected, however, more to the variety in the size than to the size itself. The same apparatus was required for setting blocks either of 20 tons or 10 tons, and the cost was as much for the latter as for the former, though only half the quantity of work was done. The answer to that probably would be, that to bond the work there must be blocks of different sizes. He thought, however, that bonded work was a mistake; the blocks should be of uniform size, resting upon one another, and in no case should one block rest upon two. It was admitted that a block might bridge over a settlement, so as not to rest upon the one below, in which case the latter might be drawn out by the sea, and a hole be made in the work. That could not happen if the blocks were placed one above another in a columnar form. He entirely approved of the capping of concrete *in situ*, and particularly of its not being continuous longitudinally. He did not think it was right to attempt anything longitudinally rigid for sea work. No additional stability was gained by an increase of length in the parts. The superstructure, he believed, would be just as stable in a series of vertical slabs extending the whole width of the breakwater as in a continuous length of concrete. The Author had arrived at the conclusion, from practical considerations, that about 16 feet was the right length for the slabs; but he thought that 8 feet would be quite as good. It was of great importance that the several sections of the superstructure should be detached from one another, and allowed to have some movement, however slight, between themselves, so as to follow any settlement in the works below. It had been stated that the blocks below low water, and up to a little above low water, should be from 100 to 200 tons in weight. That, he thought, depended upon the facility with which they could be placed. If the blocks were large, there was great expense in placing them, otherwise the larger the block the better. He should be glad if some reasons were given for the particular dimensions adopted for the breakwater, namely, 35 feet in width and 11 feet above high water. The breakwater at Kustendjie was only 12 feet wide at the top. He congratulated Mr. Cay on the success of this work, and hoped that the extension of the North Pier would be equally successful.

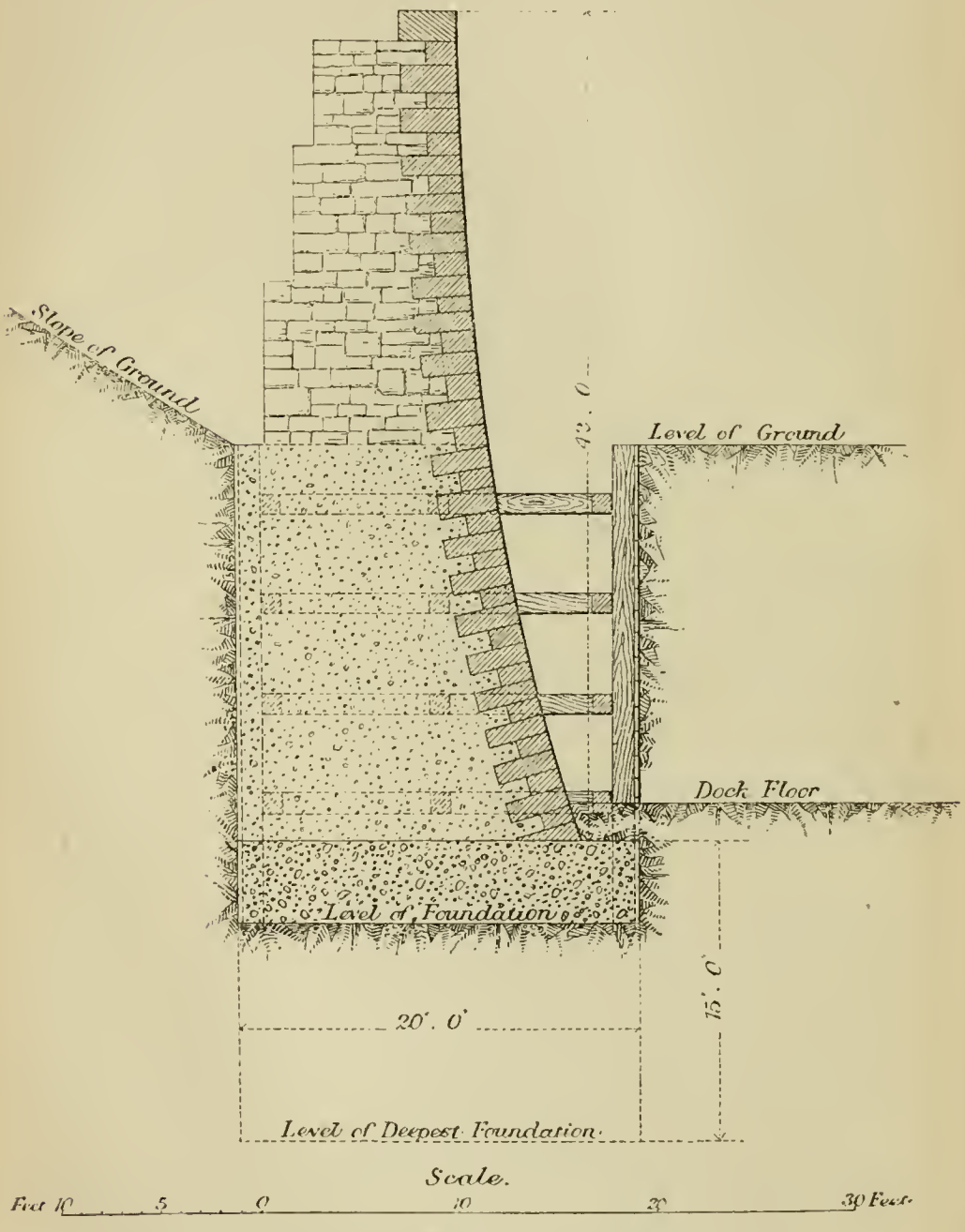
With regard to the jetty at Kustendjie, one feature of the work was the contracted space in which it had to be carried on, so that only twelve blocks could be in hand at one time. That appeared to have necessitated the adoption of the system of putting the

blocks into the work in a fresh state, when not more than twelve or fifteen days old. He had himself striven to reduce the time during which concrete blocks were allowed to set. There was a feeling among engineers, and still more among foremen, that they ought to be allowed a long time to harden. He was not of that opinion. In one case, a block of 27 tons was taken up and put in place ten days after construction, and nothing went wrong. That fact gave to the persons connected with the works some confidence, and after that they were used when a month old. If twelve or fifteen days were sufficient at Kustendjie, there was no reason why blocks should be kept occupying space even for a month. The work at Kustendjie reflected great credit on the designer, Mr. Liddell, as well as on the Author of the Paper.

Mr. Brunlees said, about six years ago he had used concrete blocks for the foundations of a dock at King's Lynn, and also concrete for pitching the slopes of the dock. Those slopes had been exposed for six years to the weather and to the bumping action of vessels, and he was glad to say they were as sound as when put down. The Papers did not deal with any great extent of work, but they were valuable in pointing out the way in which similar works might be conducted. The breakwater at Aberdeen had been, no doubt, conducted very successfully. His attention had, however, been drawn to one item, namely, that £46,000 worth of work had been done at an expense of £30,000 for plant, preparatory works, and buildings, which seemed an enormous proportion. He was at present using cement concrete for the dock at the mouth of the Avon, near Bristol. The walls (Fig. 1) were built in a trench, piles being driven on each side. Stretchers were then introduced as the excavated material was taken away. The foundations were of blue lias concrete generally to a depth of 6 feet below the level of the dock floor, but at other points, where the ground was weak, to a depth of 17 feet below the same level. On the blue lias concrete, and from 2 feet below to 18 feet above the dock floor, the wall was built of cement concrete faced with Pennant stone. The concrete was tipped into the excavation from the surface out of barrows, and at the back it was rammed against the piles and poling boards. The front of the wall was carried up in rubble at the same rate at which the cement concrete was put in. The upper part of the wall was of coursed rubble of the ordinary description. It was found that in twenty-four hours the concrete was well set. For a work of that kind, where the ground was weak and slippery, the method pursued was very appropriate, as it tended rapidly to consolidate the cement concrete, and he had every reason to be satisfied with

the results. The lias concrete cost 9*s*., and the cement concrete 14*s*. per cubic yard. To cheapen the cost of the latter he had tried mixing it with blue lias, but had not obtained the object hoped for.

Fig. 1.



Bristol Port and Channel Dock.—Section of East Wall.

Mr. Grant agreed with the Author, that it would have been better if the work below low-water level had been executed with liquid concrete in bags, instead of with blocks, as now proposed for

the extension of the North Pier. That mode would have saved a great deal of the cost of the heavy staging and plant, amounting to £23,217, or 30 per cent. of the whole cost, and also of the extra expense of making and setting the blocks. He believed, when the new work came to be carried out, that the foundation would be actually more solid than the work already done with blocks. He thought the work would have been sounder if, instead of being in sections averaging about 20 feet in length, and executed from 1 foot above low water to a height of 18 feet at one operation, it had been carried out by steps. In the Thames Embankments, from 8,000 feet to 9,000 feet in length, the mode adopted was to lay the concrete in such a way that for every foot in height there was an advance of at least 3 feet forward. By that method more perfect homogeneity of construction was secured, and the chance of vertical fractures avoided. The plan had also the advantage of graduating the work, so that no excessive weight was suddenly brought upon any part, and there was no unequal settlement. This was of great importance, not only in a constructive point of view, but in point of economy. To protect the surface from the wash of the returning tide it might be coated with Roman cement-grout or other quick-setting cement. He was of opinion that when the further works at Aberdeen were carried out, this plan would prove advantageous. The cost of the staging and plant, in proportion to the outlay, certainly seemed excessive. He had calculated the prices as follows:—Concrete deposited liquid in bags, 25*s.* 3*d.* a yard; concrete used in the apron, 44*s.* 6*d.*; concrete blocks and block-making, 13*s.*; concrete deposited liquid in frames above low-water level, 16*s.* 2*d.*; average 15*s.* 9*d.*, to which 10*s.* had to be added for plant and sea staging. The prices paid in the Thames Embankment recently finished at Chelsea were, including setting, 10*s.* 6*d.* for liquid concrete, where the proportions were 8 of gravel to 1 of cement; 12*s.* for liquid concrete, where the proportions were 6 to 1; and 16*s.* for blocks, the proportions being 6 to 1. Of course, there might be good reasons for different prices in different places; and, generally, the cost of blocks must be several shillings a yard more than the cost of liquid concrete. Every movement of heavy materials added to their cost; and in the case of cement blocks, there was not only the cost of making them, but also of moving and setting them. With regard to the cement used in the work, the specification was that the trial brick should bear a tension of 600 lbs. on an area of 2¼ inches, which was equivalent to 260 lbs. per square inch. The standard, adopted for several years by the Metropolitan Board of

Works, was 350 lbs. per square inch, or 787 lbs. on $2\frac{1}{4}$ inches. He should be glad to know the cost of rubble at Aberdeen, for the purposes of comparison. Upwards of five hundred experiments had been made for Mr. Brunlees, which justified the course taken by him for the dock near Bristol, in keeping the lime and cement concrete for different parts quite distinct. No advantage would have been gained by using a mixture of lime and cement.

Mr. G. R. Stephenson, Vice-President, thought the Paper should have contained some account of the effect of the sea upon the walls at Aberdeen. The manner in which piers were now made was very different from that formerly adopted. Many harbours were being treated simply as ditches leading from the land into the sea, and he was satisfied that was wrong. He should like to know how the work in question affected the entrance to the harbour in regard to ships going in. In these days, little or no attention was paid to the position of the piers, which ought to be such as to admit of vessels running safely in, seeing that steam-tugs were always available to tow vessels out. His impression was that the south pier was not in the best position. With an easterly or a south-easterly gale, it would be difficult for a vessel to go round the pier and get into the harbour; and when the North Pier was carried out, he thought the difficulty would be still greater, inasmuch as, he believed, the range into the harbour would be increased.

Sir John Hawkshaw, Past-President, remarked that he could not concur in the opinion that those who had to construct harbours neglected to consider the way in which vessels should get in or out. It would be a great slur upon them if they did so. He thought great credit was due to Mr. Cay for the manner in which the work at Aberdeen had been carried out, and particularly for the mode in which a portion had been constructed of concrete deposited liquid. It had apparently been forgotten that the Aberdeen breakwater was built in the sea, and not with coffer-dams in the Thames. He believed it would have been quite impossible to build the pier in the way suggested by Mr. Grant. He knew of no kind of staging by means of which the work could have been so constructed. Then with regard to the cost of concrete in the Thames and at Aberdeen, the sea was subject to storms, which stopped the work, and often prevented the men from doing more than a third of a day's work in a day, and this alone would account for the difference. Supposing the staging and plant, instead of being retained for further use, had been sold for one-fourth of the original cost, which was not putting it at too high a price, the work all round would have cost about 28*s*. per cubic yard, which

certainly was not a high figure for work of that description. It was said that all blocks below low water should be from 100 tons to 200 tons in weight. The size of the blocks, however, should have relation, not only to the sea, the particular locality, and the cost, but also to the depth at which they were placed. At Holyhead, where the water was 70 feet or 80 feet deep at the end of the breakwater, it would not be of the slightest use to employ a block of 200 tons weight, while the operation itself would be very difficult. At great depths the size of the blocks was not of much consequence. The bottom of the ocean might be composed of mud, sand, and very small gravel. If the method referred to by Mr. Grant had been adopted, in the event of a ship coming close to the side of the breakwater, the bilge would strike against the projecting concrete, and the ship might be destroyed. No general rule could be laid down ; but the work must be adjusted according to the circumstances of the case, and often according to the money to be expended. He was surprised to hear an observation with regard to the difference in the width of the two breakwaters under discussion. In many seas, a breakwater 12 feet wide would be of no more use than a sheet of paper; the sea would pass through it as soon as it was built, if it were built at all. The thickness must depend upon the impact of the sea. In some cases the thickness of the breakwater at Aberdeen would be insufficient. At Wick, a block 45 feet wide, and weighing 1,400 tons, had been moved by the sea bodily and horizontally, and shifted landwards. It was, therefore, no matter of surprise that some piers had to be made broader than others.

Mr. Alfred Giles thought it was unfair to argue that the cost of the plant was 30 per cent. of the cost of the breakwater. The southern breakwater was 1,050 feet in length, and the projected North Pier was of about equal length; the same plant would be available for both, so that the cost would only be 15 per cent. on the whole work. If a Titan were used, the foundation of the breakwater must first be made, and that would take much longer than would be required for the staging. It was thirty years since he used concrete deposited liquid *in situ*. He did not employ bags, but discharged the concrete across a lock entrance by means of a shoot. If the 100-ton bags used at Aberdeen burst when they got to the bottom, he thought a shoot would be quite as efficacious, and much more economical, and would probably answer in the construction of the North Pier. He should be glad to know whether any advantage had been found to result from the use of fresh water instead of salt water for the concrete. As the

breakwater, including a great part of the staging, was executed at a cost of £65 per lineal foot, there was not much to complain of in respect to the general expense. He thought there was not the slightest analogy between the cost of work on the river walls of the Thames and that at an exposed place like Aberdeen.

Mr. ABERNETHY remarked that the old breakwater was originally constructed in 1812 by Mr. Gibb, the then resident Engineer, who consulted Mr. Telford on the subject. The object was not to protect the entrance of the harbour, but the piers then in progress. Mr. Telford pointed out that if the old south pier was not extended parallel with the north pier to the full length, the effect would be a contraction of the harbour entrance and the formation of a shoal within the north pier-head. That result followed, and the state of the harbour entrance from 1812 until the end of last year was just as had been anticipated. It was obvious that as the end of the breakwater was immediately opposite the termination of the north pier, it could afford no protection from south-easterly seas, and that the danger to vessels entering during those gales would be increased. Therefore, as far back as 1846, the subject of moving the breakwater farther seaward was brought before the Harbour of Refuge Commission, and again in 1850 before the Harbour Commissioners of Aberdeen, also in 1860 and 1862. In 1867, Mr. Cay, adopting suggestions that had been thrown out for many years, brought forward a plan for the removal of the breakwater seaward and the extension of the North Pier. With certain modifications in the direction of the breakwater, and also in the details of the North Pier, made by Sir John Hawkshaw and himself, the plan was being carried out. Mr. Cay deserved great credit for the way in which he had completed the work, and for the substitution of concrete deposited in a liquid condition for blocks above low water. With regard to the section of the North Pier to which reference had been made, no doubt the bags would form an excellent foundation, but they should not be carried up to the level indicated, because there would be an open joint along the whole face between the mass of solid concrete and the bags so deposited. He was of opinion that blocks of concrete, or concrete *en masse*, should be carried considerably below the level of low-water.

Mr. CAY, in reply upon the discussion, said the staging was determined on before the bags were thought of, and was meant to serve for building the blocks. The staging was preferred to a Titan crane, as, to make rapid progress, the latter would have required an almost impracticable extent of overhang, owing to the

arrangement of the bond of the blocks, the height of the work, and the foundations, the excavations for which had to be prepared in advance of the building. Under these circumstances it was unreasonable to charge the expense of the staging exclusively against the bag-work in the foundations. The cost should be charged to the concrete blocks and to the apron. In reference to the relative expenditure, the plant and buildings were intended to be used for another similar work at Aberdeen. That under discussion was shorter than had been originally intended, so that the cost of the plant should be distributed over a larger amount of work than had been described in the Paper. As the working season in each year was short, the exposure great, and the total expense and risk depended very much on the number of years occupied, the use of a powerful plant was advisable and economical. In any case the relative cost of the plant for sea-works should not be compared with that for structures on shore, or in the interior of harbours.

Making allowance for part of the cost of the plant, buildings, &c., being charged against the northern extension, or for their being sold, and adding for some expenditure incurred since the 30th of September, 1873, the following was the revised statement of the work and expenditure :—

	Cubic yards.	£.	s.	d.	£.	s.	d.
Excavating for the foundations of breakwater	..	3,869	14	7			
Concrete deposited liquid in bags in the foundations	3,202	4,045	5	2			
Ditto ditto in apron, including part of the cost of the plant	1,336	2,052	1	9			
Concrete blocks and block-making	22,851	14,839	6	7			
Block-setting	ditto	3,350	18	10			
Concrete deposited liquid in frames above low-water level	23,972	19,741	13	8			
Lighthouse	..	353	9	8			
					48,252	10	3
Preparatory works					2,796	14	9
Buildings					1,107	12	11
Plant					6,319	8	5
Sea staging					8,311	18	8
Sundries					1,309	5	6
		Total			£68,097	10	6

That sum deducted from the total expenditure left £9,878 2*s.* 4*d.* as the value of plant, buildings, rails, masts, and materials in hand to be charged to other works, or to be sold. Dividing the expense of plant, buildings, staging, &c., in due proportions over the dif-

ferent parts of the work, their relative cost was approximately as follows:—

Description of Work.	Cubic yards.	Approximate price. £.	s.	d.	£.	s.	d.
Excavating for the foundations of the break-water	..	..			4,904	14	7
Concrete deposited liquid in bags in the foundations	3,202	1	15	5	5,712	16	5
Ditto ditto in apron	1,336	1	17	0	2,473	15	2
Concrete blocks and block-making	22,851	0	16	1	19,259	3	3
Block-setting	ditto	0	11	5	13,079	17	8
Concrete deposited liquid in frames above low-water level	23,972	0	18	7	22,283	13	9
Lighthouse	..	..			383	9	8
Total as above					£68,097	10	6

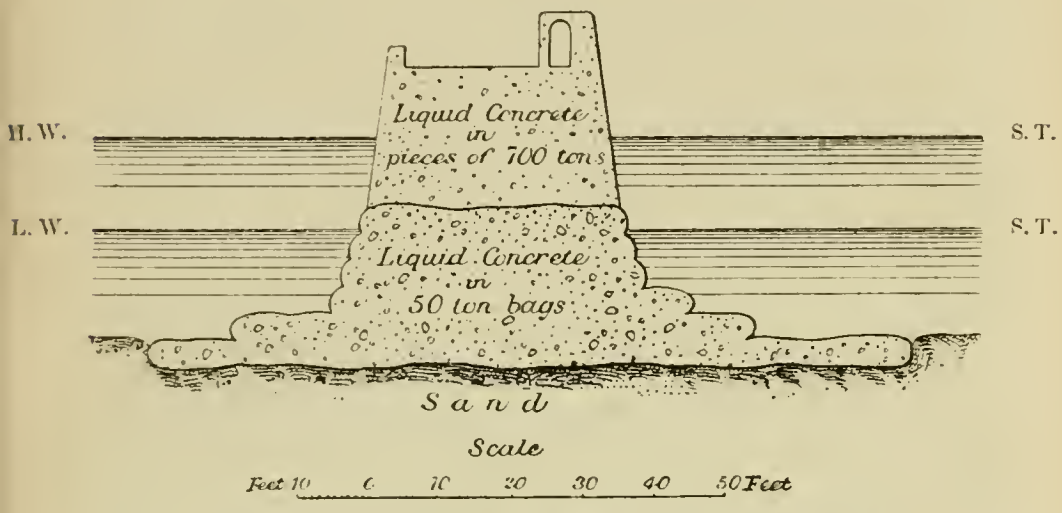
Had the breakwater been carried out to the length originally intended, it would have cost about £10,850 additional, making a total of £78,947 10*s.* 6*d.*, which agreed closely with the preliminary estimate.

The item for excavation for the foundations referred to the removal of loose stones, gravel, and sand, which would be requisite under any system of procedure, so that its cost should not properly be taken into account in the comparison; the expense of this preliminary work, however, for that part of the breakwater founded on bags was about 2*s.* 4*d.* per superficial foot. As the cost of the bag-work per cubic yard was £1 15*s.* 5*d.*, and that of a corresponding bulk of concrete block, for which it was substituted, was £1 7*s.* 6*d.*, the sum to be charged to the expense of preparing foundations by this system was 7*s.* 11*d.* Each square yard required on an average $\frac{4}{5}$ cubic yard of concrete in bags; thus the cost per square yard was 6*s.* 4*d.*, or per square foot about 8½*d.*

In the extension of the North Pier, about to be carried out, a section of which was shown in Fig. 2, and of which a model was exhibited, the foundation was sand, with solid ground at a depth of 7 feet below the surface. The whole of the submarine part, from the foundations to about 3 feet above L. W. O. S. T., a height of 22 feet, was to be formed of bags, each containing 50 tons of liquid concrete. A wide platform of these bags would be first laid as a foundation, and would be left to settle into the sand. When consolidated by the action of the waves, bags of concrete would be deposited on it, so as to bring the surface above low water, above which the work would be entirely of concrete deposited liquid in frames, in pieces of about 700 tons each. The 50-ton bags would

be deposited by a hopper barge, similar to that used for depositing dredgings, except that the slope of the well in the middle of the vessel would be modified. The precise spot for the bags would be fixed by lines ranged at right angles to one another by marks

Fig. 2.



Aberdeen Harbour.—Proposed Extension of North Pier.

on the shore and the pier, and the barge would be securely moored during the operation by six chains and rope warps, with six winches on deck for heaving on them and bringing the barge to its proper position. The contract price for such a barge delivered at Aberdeen was £2,302; that of a barge to deposit 100-ton bags of concrete was only £3,300; and though its first cost was £1,000 more than the vessel for depositing 50-ton bags, owing to fewer workmen and less time being required to deposit a given quantity of concrete, the larger vessel would be the cheaper of the two to employ in a work of great size.

The New South Breakwater had answered the purpose intended, and vessels could now enter the harbour during southerly or south-easterly gales. The only danger at present to be apprehended during storms was from the breaking seas caused by the shallow water on the bar; this danger it was expected that the extension of the North Pier would obviate, as thereby a greater depth of water at the entrance would be secured and the bar be removed. An increase of depth of 10 feet was expected to be obtained at the entrance by the combined effects of dredging and the extension of the North Pier by 1,000 feet.

Sir John Coode, through the Secretary, remarked that he had

been the first to employ Portland-cement concrete for the external work of sea piers, having so used it about ten years since, not only for the facing of the main walls, as well as for the backing, but also in parapets, copings, and paving blocks in a pier exposed to the North Sea. He had also largely and continuously adopted it since that time in other sea works. He was glad, therefore, to find that the use of concrete for building breakwaters was rapidly extending, for his confidence in this material increased as time progressed. It would have been an advantage if more definite information had been furnished as to the extent to which the concrete in the 100-ton bags had suffered by the fall, when dropped from the box supported on brackets, as described in the Paper on the Aberdeen breakwater. The system of forming concrete foundations by bags deposited from iron skips had been successfully employed, and it was believed for the first time in the United Kingdom, in some sea walls constructed under Mr. James Barton, M. Inst. C.E., at the New Harbour at Greenore, in Carlingford Lough; and the deposition of liquid concrete *in sitû* within three-sided frames lined with bagging had also been effected in a steam-packet pier at Douglas, in the Isle of Man, prior to its employment at Aberdeen. From the experience gained at Douglas, Sir John Coode could recommend the practice for moderate depths of water, especially where the bottom on which it was required to found the work was rocky and uneven; but this, like every other system, had its drawbacks, and was not suitable for all cases.

Mr. Stoney observed, through the Secretary, that the deposition of 100-ton masses of concrete in bags was an ingenious and valuable addition for protecting the toes of breakwaters in comparatively shallow water, where the depth was not sufficiently great to prevent the waves moving an ordinary rubble foreshore, composed of stones of from 3 tons to 4 tons in weight. This would in most localities vary from 9 feet to 12 feet below low water; at greater depths, stone would be much cheaper than, and equally efficacious as, large bags of concrete, which in the Aberdeen breakwater apparently cost £2 4*s.* 6*d.* per cubic yard. For the extension of the North Pier it was proposed to use large blocks of concrete of from 100 tons to 200 tons deposited liquid in bags, to form that portion which was below low-water level. Mr. Stoney thought there would be some difficulty in this, in consequence of the tendency of such large soft masses to spread and burst the bags, unless deposited within frames. However, the Author's experience might have suggested means of overcoming this difficulty. Mr. Stoney had, about six years since, successfully deposited a

large quantity of concrete under water in ordinary sacks, such as those used for holding corn. Each sack contained 6 cubic feet of concrete, which weighed a little more than 8 cwt. The cost of the sacks was at the rate of 3*s.* 2*d.* per cubic yard of concrete, but this item might probably be reduced if a large quantity of sacks were bought by contract. When laid in tiers over each other, an upper tier fitted into the inequalities of the one below, and though the cohesion of sack to sack was not equal to that of concrete to itself without the interposition of sacking, yet they dovetailed into each other and formed a capital wall so long as the foundations were unyielding. In this respect he fully agreed in the remark, that blocks of 10 to 20 tons in the lower part of vertical breakwaters, similar to that at Aberdeen, appeared to be their weak part, for, if the foundations turned out to be soft material, a slight yielding would allow the blocks to be loosened and broken up by heavy seas. Moreover, it must always be difficult, if not impossible, to thoroughly bed these blocks when under water, for mortar could not be laid between them, and, consequently, the majority of such blocks must be supported at their ends only, or unequally. For this as well as other reasons, large blocks of from 300 to 500 tons each would form the best substratum of a vertical wall. Mr. Stoney believed the only feasible method yet proposed for the purpose was that he had already described[1] for building large blocks on *terra firma*, and then conveying them afloat to their destination in fine weather. He might add that the blocks now being employed at Dublin Harbour were 29 feet in height, or 2 feet higher than those described in the Paper. The loss of iron tie-rods in masses of concrete built within frames might be obviated by placing two narrow boards, nailed together in the form of an inverted V, over the tie-rod before throwing the concrete around it. This would form a small tube in the mass, and permit the withdrawal of the tie-rod when the concrete was hard.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 332.

ANNUAL GENERAL MEETING.

December 22, 1874.

THOS. E. HARRISON, President,

in the Chair.

The list of members nominated as suitable to fill the several offices in the Council was read.

Messrs. C. Frewer, H. Hayter, C. E. Hollingsworth, Rob. C. May, T. M. Smith, F. Stevenson, and Joseph Taylor, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Ballot having been declared open, the Annual Report of the Council, on the proceedings of the Institution during the past year, was read. (*Vide* page 162.)

Resolved,—That the Report of the Council be received and approved, that it be referred to the Council to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Alfred Rumball (acting for William Lloyd) and John Thornhill Harrison, for the comprehensive statement of Receipts and Payments they have prepared; and that Messrs. John Thornhill Harrison and Charles Frewer be requested to act as Auditors for the ensuing year.

Mr. Lloyd returned thanks.

The Telford and Watt Medals, the Telford and Manby Premiums, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 178 and 179.)

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Stephenson, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Harrison, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Harrison, President, returned thanks.

Resolved,—That the best thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their unremitting and zealous services on behalf of the Institution and of the profession.

Mr. Manby and Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected:—

President.

THOMAS ELLIOT HARRISON.

Vice-Presidents.

William Henry Barlow, F.R.S.	George Willoughby Hemans.
John Frederic Bateman, F.R.S.	George Robert Stephenson.

Other Members of Council.

Members.

James Abernethy.	James Brunlees.
Sir W. G. Armstrong, C.B., F.R.S.	Sir John Coode.
Sir Joseph Wm. Bazalgette, C.B.	William Pole, F.R.S.
George Berkley.	Charles William Siemens, F.R.S.
Fred. Jos. Bramwell, F.R.S.	Sir Jos. Whitworth, Bart., F.R.S.
George Barclay Bruce.	Edward Woods.

Associates.

Major J. U. Bateman-Champain, R.E.
John Head. Colonel Charles Pasley, R.E.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hayter, Hollingsworth, May, Smith, Stevenson, and Taylor, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

ANNUAL REPORT.

Session 1874–75.

The Council, on undertaking the direction and management of your affairs, enter into an obligation to draw up a report on the state of the Institution, to be read at this meeting. That obligation they now proceed to discharge, in the full assurance that the condition of the Society will be found in all respects eminently satisfactory.

The Roll of the Institution.

Much attention has been necessarily given to the numerous and increasing applications for admission, and especially to the classification of the applicants. Many candidates desire to be at once recommended for election as Members, but on this point the bye-laws and regulations are clear and precise; and unless a candidate has had the responsible professional charge, for at least five years, of the execution of adequately important works "in some of the branches defined by the Charter[1] as constituting the profession of a Civil Engineer," he cannot be nominated

[1] The nature and objects of Civil Engineering were described by the late Thomas Tredgold, Hon. M. Inst. C.E. (*vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 181); and an abstract of his definition was subsequently embodied, as follows, in the Royal Charter of Incorporation which was granted to "The Institution of Civil Engineers" on the 3rd of June, 1828:—

"A Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer; being the art of directing the great sources of power in Nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power, for the purposes of commerce; and in the construction and adaptation of machinery, and in the drainage of cities and towns."

for Membership. The requirements are strict, but justly so; and it is believed that any relaxation in these regulations would be prejudicial to the interests of the Institution, as well as of the profession of which it is the representative. When the rules were first framed, it was anticipated that Associates might, subsequently to their election, become qualified for Members, and provision was accordingly made for their transfer. During the past session the Council have had the pleasure to raise 23 Associates to the class of Members, as reported at the Ordinary Meetings. Of the new candidates 23 were elected Members, while out of the 170 who were passed as Associates, 5 declined or failed to complete their elections.

Some dissatisfaction has been expressed with the present definition of the class of Associates. In the bye-laws, Associates are described as persons "not necessarily Civil Engineers by profession, but whose pursuits constitute branches of Engineering, or who are, by their connection with Science or the Arts, qualified to concur with Civil Engineers in the advancement of professional knowledge." There is reason to believe that many young professional men, who wish to join the Institution, but who are not yet fully qualified for the rank of Member, think it a hardship that they should be called by a name which does not imply full fellowship, and should be classed with persons "not necessarily Engineers." It must be recollected that the condition of the profession has much changed of late years; and it may be open for consideration whether some modification cannot be devised, which, while retaining an honourable distinction for the more experienced members, will yet afford a just recognition of the position of their younger brethren.

In the past twelve months there has been an effective addition of 26 Members and of 110 Associates, 39 of the latter having previously been Students: the Honorary Members remain the same. Five years ago the numbers of the three classes composing the Corporation were 16 Honorary Members, 655 Members, and 920 Associates, together 1,591; now these numbers are 15, 792, and 1,323, making the total 2,130 of all grades, and representing an accession of 539, or 34 per cent. nearly, in the interval. But in that period the Members have only increased 21 per cent., while the increase of Associates has been 44 per cent. In other words, on the 30th of November, 1869, the proportions of the three classes were 10, 412, and 578 per thousand; now the proportions are 7, 372, and 621 per thousand, showing a growing preponderance in the Associate class. The particulars of the

various alterations, and the numbers of the different grades, in the last two sessions, are recorded in the subjoined table.[1]

The Institution is approaching the close of the 57th year since its foundation. Dividing that term into three equal periods, it may be stated that at the end of the first epoch, 1818–36, the Corporation consisted of 252 members of all classes, at the end of the second, 1837–55, the number was 787, and now at the termination of the third, 1856–74, it is 2,130, without including the class of Students.

The death rate during the past year has been 19 per thousand upon the present number of members; but this, as might be surmised, was not equally distributed, for the rate was 24 per thousand among the Members, and only 16 per thousand in the case of the Associates, owing no doubt to the larger proportion of young life in the latter class. The deceased Members had belonged to the Institution for periods varying from 44 to 5 years, the average being nearly 21¼ years; while the Associates had been on the books for periods of from 35 to 4 years, the average in this case being 17. The list of deceases contains the names of several well-known and distinguished engineers, who added to the lustre and increased the renown of the profession. In the follow-

[1] The tabular statement for the years 1872–73 and 1873–74, of the transfers, elections, deceases, resignations, and erasures of the members of all classes belonging to the Corporation, that is, exclusive of the Students, is as follows:—

Year.	Honorary Members.	Members.	Associates.	
1872–73.				
Transferred to Members . .	..	..	13	
Elections	..	17	137	154 — 43 = 111
Deaths	1	10	17	
Resignations	..	2	4	43
Erased from Register . . .	..	4	5	
Members of all Classes on the Books, 30th November, 1873	15	766	1,213	1,994
1873–74.				
Transferred to Members . .	..	..	23	
Elections	..	23	165	189 — 53 = 136
Restored to Register . . .	..	..	1	
Deaths	..	19	21	
Resignations	..	..	7	53
Erased from Register . . .	..	1	5	
Members of all Classes on the Books, 30th November, 1874	15	792	1,323	2,130

ing list the figures against the several names indicate the number of years each member had been on the register:—

Members: Henry Baylis (7), Sir John Benson (12), George Black (9), John William Blackburne (5), George Clarisse Dobson (34), Sir William Fairbairn, Bart., *F.R.S.* (44), Sir Charles Fox (36), John Grantham (34), John D'Urban Hughes (33), Thomas Marr Johnson (22), William Blake Lambert (25), Thomas Login (6), William Martley (7), William Richard Morris (8), Henry James Walton Neville (10), Sir John Rennie, *F.R.S.*, Past-President (30), James Samuel (25), Frederick Albert Winsor (39), and Thomas Alfred Yarrow (17).

Associates: James Allan (25), Thomas Bell (20), Lieut. Gordon Bigsby, *R.E.* (7), Robert Broad (8), Thomas Gaul Browning (12), William Crosley (24), James Benjamin Dunn (15), Cornelius Willes Eborall (9), Ralph Elliot (8), Joseph Samuel Forbes (4), Sir Richard Atwood Glass (16), Thomas Grissell (35), James Innes Hopkins (4), Edward Barber Humble (8), Sampson Lloyd (17), Sir Harry Stephen Meysey-Thompson, Bart. (8), John Roe (32), Sir Francis Pettit Smith (26), General Sir John Mark Frederic Smith, *K.H.*, *R.E.* (33), William Woodcock (19), and Charles Favell Forth Wordsworth, *Q.C.* (23).

The names of the following members, who have signified, in writing, their desire to resign, have been withdrawn from the list:—

Member: Charles Baxter Cousens.

Associates: Frederick Robert Browning, Herbert Bland Browning, William Harker, Francis King, Lieut.-Col. William Lawtie Morrison, *R.E.*, Sir George Frederick Verdon, *C.B.*, *F.R.S.*, and Edward Romilly Willis.

The Students attached to the Institution.

When it is remembered that no one can become a candidate for election into the Corporation until he is upwards of 25 years of age, the necessity for a junior class will be apparent. Moreover, both in the best interests of the Corporation and of the profession, it is essential that every engineering pupil should at the very outset of his career be recognised by, and be attached to, the Institution. Before the Student class was organised, young engineers were, to a large extent, excluded, by the limitation of age, from the benefits of the Society. Now that class may be looked upon not only as a feeder, but as introducing to the body regularly trained engineers. It is therefore gratifying to the Council to be able to report that 82 candidates were admitted Students

during the last session, and that the effective increase in the year has been 23, bringing up the total to 282.

It has been under consideration whether any alterations should be proposed in the rules respecting the class of Students. They are now simply recommended for admission by the Members or Associates under whom they are, or have been, in the course of preparation and training for the profession, and on such nomination they have been admitted. It has been suggested that, if the present mode of admission be continued, engineers should take as pupils only those who have received a special scientific education, or who have shown, by examination, that they possess certain preliminary knowledge of a kind likely to fit them for becoming Engineers. The question is, however, so intricate, that at present the Council are not prepared to make any definite recommendations; but it will continue to receive the attention which the importance of the subject demands.

Finance.

The broad features of the cash statement annexed to this Report, as certified by the Auditors, may be briefly indicated. Last year the gross receipts were nearly £9,000, in the twelve months just concluded they have reached £10,000; then the ordinary expenditure was about £6,000, now the total payments have amounted to £7,000. This excess in the disbursements is in part due to increased establishment charges, but is mainly owing to the liabilities incurred for the "Minutes of Proceedings," the publications being debited with the large sum of £3,115. That sum, however, represents part of the expense of publications which in the ordinary course would have been included in the next year's accounts, and is therefore more than the cost of two such volumes as have lately been issued annually. The Council, looking at the cash balance in hand, has deemed it expedient to make this anticipation in the regular time of payment on account of work done by the printer and the engraver, and thus to secure an extra discount. A more exact analysis of the financial statement shows that the subscriptions alone, with dividends on Institution investments, forming the income proper, amounted to £7,310 13*s.*; that the Telford, Manby, Miller, and Howard Trust Funds realised £447 17*s.* 5*d.*; and that the life compositions, the admission and building fund fees, and a further small sum from the residuary estate of Mr. Telford,—all which are treated as capital, and invested accordingly,—produced £1,931 7*s.* 2*d.* Certain miscellaneous items, yielding to-

gether £301 17*s.* 11*d.*, had not been included in the revenue named, as they were in the nature of set-offs to expenditure. After allowing for these, as well as for the outlay on account of premiums under trust, £240 9*s.* 8*d.*, the net expenditure became £6,488 1*s.* 4*d.*

Investments.

The further small sum of £14 11*s.* 8*d.* received from Mr. Telford's estate, and the balance of income on this account, £51 2*s.*, not expended in 1873, were invested in £15 15*s.* 10*d.* and £55 10*s.* 9*d.* Three per cent. Annuities, thus raising the nominal capital of the original bequest to £5,425 11*s.* 5*d.*, and of the accumulations of dividends to £3,070 8*s.* 1*d.*, together, £8,495 19*s.* 6*d.* In like manner the accumulations of the Miller Fund were increased to the extent of £136 18*s.* 3*d.* Annuities, representing £125 19*s.* 1*d.* not expended in 1873, bringing up the par value of such accumulations to £1,576 11*s.* 9*d.* in addition to that of the original bequest of £3,100, together now standing in the books at £4,676 11*s.* 9*d.* On the Institution's account a sum of £2,805 18*s.* 2*d.* was invested in the purchase of £750 Great Northern Railway, £500 London and North-Western Railway, £500 London, Brighton, and South Coast Railway, and £1,000 Lancashire and Yorkshire Railway Four per cent. Debenture Stocks, by which the holding of the Corporation in each of these several stocks has been raised to £3,000 at par value.

The Funds.

The securities representing the various investments are annually inspected by the Auditors, when preparing the Abstract of Receipts and Payments. From that Abstract, it will be found that the Funds now belonging to, or under the charge of, the Corporation —the details of which are given—are as follows :—

	£.	s.	d.
Institution Investments	18,994	1	8
Trust Funds	13,924	5	9
Total nominal or par value . . .	32,918	7	5
Cash in hands of the Treasurer . . . £241 14 10			
Less petty cash due to the Secretary . 1 8 11			
	240	5	11
Together amounting to . . .	£33,158	13	4

as compared with £30,223 8*s.* 6*d.* at the date of the last Report.

Of these Funds a sum of £11,968 7*s.* 5*d.* is placed in Government Stocks, and £20,950 stands in nearly equal proportions in guaranteed stocks of seven of the principal railway companies.[1] The investments yield an average rate of interest of $3\frac{3}{5}$ per cent.

The Ordinary Meetings.

The "Minutes of Proceedings," vols. xxxvii. and xxxviii., having been issued during the recess, the members will be aware that twelve Original Communications were read and discussed, at the twenty-three Ordinary Meetings of the past session. A brief allusion to the contents of these volumes will suffice to show the variety and interest of the topics that have engaged attention during the period under review. The Papers related to the following subjects—Modern Locomotives, designed with a view to economy, durability, and facility of repair, together with some particulars of the duty performed and of the cost of repairs; the construction and maintenance of the Harbour at Braye Bay, Alderney; the geological conditions affecting the construction of a Tunnel between England and France; the Mechanical Production of Cold; the Portslade Gasworks, belonging to the Brighton and Hove General Gas Company; the construction of Harbour and Marine Works with artificial blocks of large size; the works for the Supply of Water to

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[1] The following is a summary of the different securities in which these Funds are placed:—

	£.	s.	d.	£.	s.	d.
Government Stocks:—						
Three per Cent. Consols	5,799	19	6			
Three per Cent. Annuities	3,946	4	0			
New Three per Cents.	2,222	3	11			
				11,968	7	5
Great Eastern Railway:—						
Five per Cent. Preference Stock	200	0	0			
Four per Cent. Debenture Stock	4,750	0	0			
				4,950	0	0
Lancashire and Yorkshire Railway:—						
Four per Cent. Debenture Stock				3,000	0	0
London and North Western Railway:—						
Four per Cent. Debenture Stock				3,000	0	0
London, Brighton, and South Coast Railway:—						
Four per Cent. Debenture Stock	1,500	0	0			
Four and a Half per Cent. Debenture Stock	1,500	0	0			
				3,000	0	0
North Eastern Railway:—						
Four per Cent. Debenture Stock				3,000	0	0
Great Northern Railway:—						
Four per Cent. Debenture Stock				3,000	0	0
Manchester, Sheffield, and Lincolnshire Railway:—						
Four and a Half per Cent. Debenture Stock				1,000	0	0
Total nominal or par value				£32,918	7	5

the City of Dublin; the Great Basses Lighthouse, Ceylon; the tracing and construction of Roads in Mountainous Tropical Countries; Gun-carriages and Mechanical Appliances for working Heavy Ordnance; the Fixed Signals of Railways; and Peat Fuel Machinery.

To the Authors of several of these communications Premiums have been awarded, out of the special Trust Funds bequeathed or assigned for the purpose, as follows: Telford Medals and Premiums to Bindon Blood Stoney, M.A., Richard Christopher Rapier, and Joseph Prestwich, F.R.S.; Watt Medals and Telford Premiums to Alexander Carnegie Kirk and George Wightwick Rendel; Telford Premiums to Major James Browne, R.E., William Douglass, and Joseph McCarthy Meadows; while the Manby Premium was adjudged to Leveson Francis Vernon-Harcourt, M.A.

The Supplemental Meetings.

The Students assembled on ten evenings. On each occasion a Paper was read by a member of that class, the Meetings being presided over, as a rule, by one of the Council. Miller prizes were awarded to some of the writers as follows: viz., to James Charles Inglis, Matthew Curry, jun., Walter Young Armstrong, Charles Graham Smith, Alfred Fyson, and George Edward Page. The most satisfactory communications were those descriptive of works actually executed under the eyes of the respective Authors, and these gave rise to well-sustained discussions. A few, however, evinced a lack of originality, and one contained hardly anything relating to engineering science, but was principally devoted to speculations. The Meetings were better attended than in the previous year, but still not so well as might be expected, considering the advantages they afford for mutual improvement.

As an additional incentive and encouragement to the Students, it has been determined to establish a series of Scholarships, to be called "The Miller Scholarships of The Institution of Civil Engineers," and to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years, as a reward for the best Paper written by a Student, always supposing the best Paper to be sufficiently important.

Invitations for Papers.

In accordance with custom, the Council have issued a List of Subjects on which Papers are invited, and have this year prefixed to the list a statement of the nature and amount of the

funds at their disposal for rewarding the Authors of meritorious Original Communications on any subjects of engineering interest (*Vide* page 180). They trust that members of all classes will earnestly aid in the endeavour to keep up, and, if possible, raise, the character of the Papers, which should advance in importance and in merit, in proportion as the operations of the profession extend. While the Society was young, it was felt to be essential to obtain and to record the best and most complete data as to works actually executed, and the invitations were aimed mainly at subjects of this kind. But now that practical construction has become much more widely known, and that information upon it is so readily accessible, communications of this class, to be of real value, should present remarkable points of special interest or novelty.

The Council feel that what should now be encouraged are Papers embodying careful thought and intelligent study rather than bare description. There is no lack of examples of high-class essays on engineering topics, and no lack of subjects offering abundant scope for others. It has already been intimated that memoirs will be received on projected works, when such memoirs relate to *bonâ fide* undertakings, and deal with the discussion of important scientific engineering problems, provided the Papers are submitted with the sanction of the engineers responsible for the works in question. And further, any scientific essay which has a practical bearing on engineering operations will be acceptable. The Council venture to hope that many highly educated and experienced engineers will be prepared to contribute communications of a character to do honour to the body to which they belong.

The Council have thought it right to subject all Papers to a more searching examination than heretofore; and while they offer a welcome reception to any contribution, if it shows original merit, they will be compelled to exclude merely commonplace descriptions of ordinary works, which descriptions, as they have pointed out, are no longer of the same use as in former days.

The Publications.

The Council have continued to give earnest attention to the Publications, for as the number of members who can attend the Meetings must form a very small proportion of the whole body, the publications afford the chief evidence on which the Institution will be judged by the generality of the profession, as well as by

the scientific world, and constitute the principal bond of union among the members, who are dispersed over every portion of the globe. For these reasons it is highly important not only that a full and faithful transcript of the proceedings of the Meetings should be presented, but that the publications should be creditable both in a scientific and in a literary point of view.

In pursuance of the announcement in the last Report, active steps have this year been taken to extend the scope and to increase the contents of the publications. In that report it was stated that, in addition to the ordinary Minutes of Proceedings, such Papers as had been accepted but not read might be formed into a second section. It was also announced that "a summary of information, gathered from the transactions of foreign engineering societies, and from foreign scientific periodicals," would be added as a third section, so as to render the Minutes "a perfect record, however brief, of the progress of engineering science." A few years ago the proceedings were contained in one annual volume of 540 pages, afterwards expanded into two volumes together of 944 pages. Now it is proposed to issue one volume of about 350 pages as early in each quarter as circumstances will permit.

With regard to the projected "summary of information from foreign transactions and periodicals," it was decided that a mere notice where such information might be obtained would be but of little practical value. As many members have not time to peruse the original articles, it was deemed expedient that the most important portion of each article should be abstracted with as much brevity as was consistent with clearness, so that each abstract should afford definite information. Articles descriptive of engineering works in progress or completed, of mining operations, of railways, of sanitary works, of telegraphs, and treatises of a theoretical character, will be embodied in this section. It may be objected that a notice of any work of real importance is certain to have appeared previously in some other publication. But even if this should be the case, it has been found, as a matter of experience, that the information thus given is often disconnected, not usually from responsible authorities, nor always treated in the professional manner to which the members have become accustomed. Besides, such other publications may not at all times be within reach. It is believed that by the changes now being made in the "Minutes of Proceedings," members in the most remote regions will be periodically informed not only of what is going on at home, but also of every important transaction which takes place abroad.

In the selection of the abstracts, and generally in arranging the work, it has been thought expedient to follow the mode of procedure adopted by other societies whose publications contain abstracts on the same principle. There has gradually been assembled round each of such publications a staff of members actuated by a public spirit, and willing to devote their talents and time to the furtherance of knowledge. It is earnestly hoped that so laudable an example will be followed, and that members who are in a position to furnish abstracts on subjects with which they are specially acquainted, will consider it a pleasure, and deem it a duty to lend their aid.

It has, however, been found, not without a certain satisfaction, in looking through from sixty to seventy periodicals, representing the United States and almost every country in Europe, that but few of them equal in interest and in practical character our "Minutes of Proceedings." There is, however, an amount of information to be gathered from them, more than sufficient to fill the 120 pages which it is proposed to devote to this section. Every pains will be taken to include in these pages correct abstracts of the scientific memoirs which have rendered the foreign academies and their theoretical writers so justly celebrated.

Catalogue of Engineering Information.

Doubtless many members know that there has lately been completed, under the auspices of the Royal Society, an elaborate "Catalogue of Scientific Papers," consisting of those published from 1800 to 1863, in all parts of the world. This work is acknowledged to be of the greatest utility; and it may be well to ascertain whether something analogous, but confined to information on engineering subjects, cannot be undertaken with advantage.

A catalogue of the Library, as well as a classified index to the "Minutes of Proceedings," already exist, but, from not being sufficiently general, neither answers fully the purpose intended. Engineers in practice are aware how often occasions occur when it would be very useful to know what has been done in certain cases, or the amount and kind of information on record in regard to particular subjects; but in the vast and ever-increasing mass of engineering literature, a search for such data without guidance is almost hopeless. In these cases a comprehensive catalogue of the kind referred to would be invaluable.

The compilation of a work like this would involve expenditure both of time and of money, and the arrangements for it would require careful consideration; but the Council think the object is well worthy the attention of their successors in office.

Conclusion.

To represent the ever-widening fields of industries now flourishing, many of them undreamt of in the days of our founders, various societies have from time to time been established for the study of special branches of engineering science and practice. The Institution of Mechanical Engineers, the Institution of Civil Engineers of Ireland, the North of England Institute of Mining and Mechanical Engineers, the Institution of Engineers in Scotland, the Iron and Steel Institute, the Institution of Naval Architects, the Society of Telegraph Engineers, and others that might be named, come under this category. The headquarters of the majority are in the provinces, while a few hold their meetings in London.

The existence of these societies, each occupying different ground, furnishes significant evidence of the growth of the profession; and the Council, have felt it a duty to aid them, by granting the use of the rooms for their meetings, and by any other friendly offices. But, at no very distant time, the question may arise, whether some plan cannot be devised, by which there shall be a still closer tie between these societies, and the oldest association connected with the profession—The Institution of Civil Engineers.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer				279	10	6
— Subscriptions and Fees:—						
Arrears	217	7	0			
Current	6,361	2	0			
Subscriptions in advance	38	12	0			
Life Compositions	387	19	6			
Fees	589	1	0			
				7,594	1	6
— Building Fund				939	15	0
— Publication Fund				162	4	0
— Publications:—Sale of Transactions				68	9	5
— Telford Fund:—						
Dividends, 1 Year, on £2,839 10s. 6d., Three per Cent. Consols	84	5	5			
Ditto, 1 Year, on £2,586 0s. 11d., Three per Cent. Annuities	76	15	3			
Ditto, 1 Year, on £2,377 10s. 6d., Three per Cent. Consols (Unexpended Dividends)	70	12	1			
Ditto, 1 Year on £692 17s. 7d., Annuities (Ditto, ditto)	20	11	4			
				252	4	1
— Manby Donation:—						
Dividends, 1 Year, on £200, Great Eastern Railway Co., Norfolk, Five per Cent. Preference Stock				9	17	8
— Miller Fund:—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	79	1	8			
Ditto, 1 Year, on £1,100, Great Eastern Ditto	43	9	11			
Ditto, 1 Year, on £582 18s. 6d., Three per Cent. Consols (Unexpended Dividends)	17	6	3			
Ditto, 1 Year, on £993 13s. 3d., Annuities (Ditto, ditto)	29	10	3			
				169	8	1
—Howard Bequest:—						
Dividends, 1 Year, on £551 14s. 6d., New Three per Cents.				16	7	7
— Institution Investments:—						
Dividends, 1 Year, on £3,650, Great Eastern Railway Four per Cent. Debenture Stock.	144	6	5			
Ditto, 6 Months, on £2,500, London and North Western Ditto	49	7	6			
Ditto, 6 Months, on £3,000, Ditto, ditto.	57	2	6			
Ditto, 6 Months, on £1,000, London, Brighton, and South Coast Ditto	19	15	0			
Ditto, 6 Months on £1,500, Ditto, ditto	29	13	9			
Ditto, 1 Year, on £3,000, North Eastern Ditto	118	12	6			
Ditto, 6 Months, on £2,250, Great Northern Ditto	44	8	9			
Ditto, 6 Months, on £3,000, Ditto, ditto.	59	7	6			
Carried forward	£522	13	11	£9,491	17	10

from the 1ST DEC., 1873, *to the* 30TH NOV., 1874.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By Balance due to the Secretary				16	4	7
— House, Great George Street, for Rent, &c.:—						
Repairs	71	10	11			
Rent	650	6	10			
Rates and Taxes	65	14	3			
Insurance	30	6	6			
Furniture	14	18	3			
				832	16	9
— Salaries				1,300	0	0
— Clerks, Messengers, and Housekeeper				491	17	0
— Donation to late Housekeeper				30	0	0
— Postage and Parcels:—						
Postage	84	2	10			
Parcels	2	18	9			
				87	1	7
— Stationery, Engraving, Printing Cards, Circulars, &c.				229	13	7
— Light and Fuel:—						
Coal and coke	49	6	6			
Candles	0	2	0			
Gas	50	15	4			
Water for Engine	4	2	0			
				104	5	10
— Tea and Coffee				29	12	9
— Library:—						
Books	190	7	2			
Periodicals	32	9	0			
Binding Books	47	17	5			
				270	13	7
— Publication, Minutes of Proceedings				3,115	18	0
— Telford Premiums				160	16	5
— Watt Medals				7	2	6
— Manby Premium				25	0	0
— Miller Prizes				54	13	3
— Diplomas				31	14	4
— Manuscripts, Original Papers, and Drawings				6	10	2
— Annual Dinner (Official Invitations, &c.)				124	8	10
— Winding and Repairing Clocks				3	12	0
— Incidental Expenses:—						
Christmas Gifts	1	15	6			
Assistance at Ordinary Meetings	10	4	0			
Ditto at Students' Meetings	3	15	0			
Beating Carpets and Sweeping Chimneys	1	6	0			
Household Utensils, Repairs, and Expenses	91	7	3			
				108	7	9
Carried forward				£7,030	8	11

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.	£.	s.	d.	£.	s.	d.
Brought forward . .	522	13	11	9,491	17	10
To Institution Investments:—*cont.*						
Dividends, 1 Year, on £1,500, London, Brighton, and South Coast Railway Four and a Half per Cent. Debenture Stock	66	14	7			
Ditto, 1 Year, on £1,000, Manchester, Sheffield, and Lincolnshire Ditto, ditto.	44	9	8			
Ditto, 6 Months, on £1,000, Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	19	15	10			
Ditto, 1 Year, on £1,344 1s. 8d., New Three per Cents	39	18	0			
				693	12	0
— Donations to Library				33	4	0
				10,218	13	10
— Telford Fund, Further Capital Sum from Executors	14	11	8			
— Telford Premiums, Repayment of Extra Cost of Binding	23	0	6			
— Manby Premium, ditto	15	0	0			
				52	12	2
— Benevolent Fund Disbursements, 1873				9	7	10
— Balance of Petty Cash, Nov. 30, 1874, due to the Secretary . .				1	8	11
				£10,282	2	9

from the 1ST DEC., 1873, *to the* 30TH NOV., 1874.

PAYMENTS—*cont.*

Cr.				£.	s.	d.
Brought forward				7,030	8	11
By Benevolent Fund Disbursements, 1874				12	8	1
— Telford Fund.—Further Amount received from the Executors of the late Thomas Telford, invested in £15 15*s.* 10*d.*, Three per Cent. Annuities	14	11	8			
— Ditto, ditto.—Balance of Income not yet expended in Annual Premiums, invested in £55 10*s.* 9*d.*, Three per Cent. Annuities . .	51	2	0			
— Miller Fund.—Balance of Income not yet expended in Annual Prizes, invested in £136 18*s.* 3*d.*, Three per Cent. Annuities .	125	19	1			
— Institution Investments :—						
£750, Great Northern Railway, Four per Cent. Debenture Stock	766	3	8			
£500, London and North Western Ditto, ditto	510	0	0			
£500, London, Brighton and South Coast Ditto, ditto	508	5	6			
£1,000, Lancashire and Yorkshire Ditto, ditto	1,021	9	0			
				2,997	10	11
— Balance Nov. 30, 1874, in the hands of the Treasurer . . .				241	14	10
				£10,282	2	9

Examined and found correct.

(Signed) ALFRED RUMBALL,
Acting for WM. LLOYD,
JOHN THORNHILL HARRISON. } *Auditors.*

JAMES FORREST, *Secretary.*

December 4th, 1874.

PREMIUMS AWARDED.

Session 1873–74.

The Council of The Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, to Bindon Blood Stoney, M.A., M. Inst. C.E., for his Paper "On the Construction of Harbour and Marine Works with Artificial Blocks of Large Size."

2. A Telford Medal, and a Telford Premium, to Richard Christopher Rapier, Assoc. Inst. C.E., for his Paper "On the Fixed Signals of Railways."

3. A Telford Medal, and a Telford Premium, to Joseph Prestwich, F.R.S., Assoc. Inst. C.E., for his Paper "On the Geological Conditions affecting the Construction of a Tunnel between England and France."

4. A Watt Medal, and a Telford Premium, to Alexander Carnegie Kirk, Assoc. Inst. C.E., for his Paper "On the Mechanical Production of Cold."

5. A Watt Medal, and a Telford Premium, to George Wightwick Rendel, M. Inst. C.E., for his Paper on "Gun-Carriages and Mechanical Appliances for working Heavy Ordnance."

6. The Manby Premium to Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E., for his "Account of the Construction and Maintenance of the Harbour at Braye Bay, Alderney."

7. A Telford Premium to Major James Browne, R.E., Assoc. Inst. C.E., for his Paper "On the Tracing and Construction of Roads in Mountainous Tropical Countries."

8. A Telford Premium to William Douglass, M. Inst. C.E., for his Paper on "The Great Basses Lighthouse, Ceylon."

9. A Telford Premium to Joseph McCarthy Meadows, for his Paper on "Peat Fuel Machinery."

The Council have likewise awarded the following Prizes to Students of the Institution :—

1. A Miller Prize to James Charles Inglis, Stud. Inst. C.E., for his Paper on "Theory and Practice in the Construction of Tanks."
2. A Miller Prize to Matthew Curry, jun., Stud. Inst. C.E., for his Paper on "The Lisbon Steam Tramway."
3. A Miller Prize to Walter Young Armstrong, Stud. Inst. C.E., for his Paper "On the Construction of, and the Means employed to place in Position, the Cylinders of a Bridge over the Wye, at Monmouth."
4. A Miller Prize to Charles Graham Smith, Stud. Inst. C.E., for his Paper on "Practical Ironwork."
5. A Miller Prize to Alfred Fyson, Stud. Inst. C.E., for his Paper on "Details in the Construction of Docks."
6. A Miller Prize to George Edward Page, Stud. Inst. C.E., for his Paper on "Coal Gas and its Manufacture."

Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

SUBJECTS FOR PAPERS.

Session 1874–75.

The Council of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will be prepared to award Premiums, arising out of special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, given "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) now produces about £250 annually.

2. The Manby Donation, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings," of the value of £10 a year.

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) now realises nearly £165 per annum. Out of this Fund the Council have determined to establish a series of Scholarships,—to be called "The Miller Scholarships of the Institution of Civil Engineers,"—for Papers from Students, and to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The income amounts to upwards of £16. It is proposed to award this prize every five years, commencing in 1877.

The Council will not, in any case, make an award unless a communication of adequate merit is received; but, on the other hand, more than one Premium will be given, if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made between essays received from a Member, an Associate, or a Student of the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

LIST.

1. On the Flow of Fluids and Gases.
2. On Portable Apparatus for Gauging the Materials, and for the Expeditious Mixing of large quantities, of Portland Cement Concrete.
3. On the Value and Strength of the different Materials used for making Concrete: comparing, for example, Portland cement with hydraulic lime, shingle with iron slag or quarry rubbish, coarse river with fine sea sand, together with Experiments on the Proper Proportions of each, and of the Water, whether salt or fresh, to produce the Strongest Mixture.
4. On the Manufacture as now practised of Iron and Steel of various qualities; on the effect on the Strength and Tenacity of the Metal of the Admixture of Foreign Substances; on the various Experimental Tests by which the Quality may be ascertained; and on the effects of extreme Temperatures on Metals.
5. On the Process of Forging by the Hydraulic Press, and on Effects of Pressure on Cast Steel in the mould.
6. On the Results of Experience in the recent Extended Use of Steel in Mechanism and in works of Engineering.
7. On the Construction of Warehouses and other buildings for storing Goods, with the Special View of resisting Fire, and on the relative Merits of brickwork, iron, and timber for that object.
8. On the Construction of Street Tramways, the best means of adapting them for the conveyance of passenger and goods traffic, and the best method of avoiding evil and inconvenience to other carriages travelling on the same roads.
9. On Modern Methods of Constructing the Foundations of Bridges.

10. On Viaducts with Metallic Arches of Large Span, considered with special reference to the Strains resulting from changes in Temperature, and Structural Provisions for reducing or eliminating such Strains.
11. On the Design, generally, of Iron Bridges of very large span, for Railway traffic; and on the Comparative Merits of European and American Wrought-Iron Railway Bridges.
12. On Dock Gates and Caissons, including a Description of the requisite external and internal arrangements, with recent practical examples.
13. On the Appliances and Methods used for 'Tunnel Driving,' Rock-boring, and Blasting in this country and abroad, with details of the cost and of the results attained.
14. On the Permanent Way of the Railways of 1874, and the extent of its identity with the Permanent Way of 1834, in respect to the rails, fastenings, and sleepers generally; with statistical tables showing the length of road laid with the double-headed chair rail and the flat-footed rail in different countries at the present time.
15. On the Block Systems of Signalling on Railways, and on Means of Communication with trains in Motion.
16. On Sorting Sidings for Railway Trains.
17. On the Constant Service of Water Supply, with special reference to its introduction into the Metropolis, in substitution for the Intermittent System; and on the Waste of Water, and the best apparatus for its prevention.
18. On the various Modes of Dealing with Sewage, either for its disposal or its utilisation.
19. A History of any Fresh-Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works that may have been executed upon it, and of the effect of the works.
20. On the relative Value of Upland and of Tidal Waters in maintaining rivers, estuaries and harbours.
21. On the System of River and Canal Towage in use on the Continent of Europe.
22. On Recent Improvements in the Construction of Steam Boilers adapted for very High Pressures.
23. On the best practical Use of Steam in Steam Engines, and on the effects of the various modes of producing Condensation.
24. On the Results of Experiments on Steam Jacketing.

25. On the Modern Construction of Marine Engines, having reference to Economy of the Working Expenses, by Superheating, Surface Condensing, High Pressure, great Expansion, &c.
26. On the Construction of Portable Steam Engines, or other Motors, of very light weight, suitable for boats, aerial machines, &c.
27. On the relative Cost of the Conveyance of Coal by Rail and by Steamer.
28. On the various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency.
29. On the employment of Water as a Motive Power, its relative advantages and disadvantages compared with Steam Power, and the Hydraulic Motors most suitable for utilising the power in the best manner.
30. On the best Methods of Removing Grain in bulk from a Ship to a Warehouse, for distributing in the Warehouse, and on the various modes in which grain is stored in bulk.
31. On the Methods of transmitting Force to distant points; and on the Details of the existing systems of Rope Transmission.
32. On the Present State of Science with regard to the Manufacture, Purification, and Distribution of Coal Gas.
33. On the Manufacture of Mineral Oils, and the Lamps best adapted for their consumption in dwellings and lighthouses.
34. On the 'Output' of Coal in the United Kingdom, as compared with that of other countries, illustrated by statistical tables, plans, and diagrams, showing where Coal is produced, and where and how it is consumed.
35. On the Sinking to, and Machinery applied at, deep Coal Mines (in Saxony, for instance), with a notice of the modifications necessary in future Coal Mining Operations suggested (or indicated) by the working of deep sinkings.
36. On Compressed Air as a Motive Power for Machinery in Mines, with some account of its application on the Continent.
37. On the Dressing of Lead, Copper, and other Ores by any other process than that of Water.
38. On the Smelting of the Ores of Lead, Copper, Zinc, and Tin, with details of the results and cost by different methods.
39. On Pneumatic Telegraphs, and on Pneumatic Despatch Tubes, designed with a view to economical working, and to the attainment of high speeds in long lengths of pipe.
40. On recent Progress in Telegraphy, including a notice of the theoretical and practical data on which that progress has

been based, with some account of the improvements in the construction of land and sea lines and in the working instruments.

Instructions for Preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. A concise abstract must accompany every Paper.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible when suspended in the Theatre of the Institution, should be sent for the illustration of particular portions.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The communications must be forwarded, on or before the 31st of December, 1874, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where any further information may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, S.W.,*
7th July, 1874.

Excerpt Bye-Laws, Section XV., Clause 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1ST, 1873, AND NOVEMBER 30TH, 1874.

AUTHORS.

Binnie, A. R. No. 1,398.—The Nágpúr Waterworks: with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nágpúr; and on the Fluctuation of Rainfall in India and in other places.

Cay, W. D. No. 1,389.—The New South Breakwater at Aberdeen.

Chesshire, E. No. 1,392.—The Disposal and Utilisation of Sewage.

Collen, H. No. 1,408.—Barometric Pressure, a Mechanical Force?

Colson, C. No. 1,400.—Details of the Working Tests, and Observations on Portland Cement, made during the Construction of the Portsmouth Dockyard Extension Works.

Cooke, G. C. No. 1,402.—On Practical Methods of Determining the Waterway to be provided in crossing the drainage on long slopes leading to Indian Rivers.

Cross-Buchanan, W. No. 1,380.—Description of the Southern Railway of Chili.

Cudworth, W. No. 1,406.—On Sidings for Sorting Railway Trains by Gravitation.

Dawnay, A. D. No. 1,386.—On the Reconstruction of a Low Breast Vertical Water-wheel at Molewood Mill, Bengeo, Herts.

Donaldson, W. No. 1,388.—Principles of Construction and Efficiency of Water-wheels and Turbines.

Douglass, W. No. 1,394.—The Great Basses Lighthouse, Ceylon.

Gaudard, J. No. 1,405.—Notes on certain works in Switzerland, and on various Questions of Theory.

Greaves, C. No. 1,409.—On Natural or Atmospheric Evaporation from the surfaces of Land and Water; with considerations on the Fall and Percolation of Rain through Earth and Sand.

Gruningen, O. No. 1,399.—The Mount Washington Railway.

Jones, H. E. No. 1,407.—The Construction of Gasworks.

Keeling, G. W. No. 1,404.—On the Blasting of Rock below Water with Dynamite.

AUTHORS.

Martin, J. No. 1,380A.—On the various modes of dealing with Sewage for its Disposal and Utilisation.

M'Cosh, Dr. No. 1,390.—On a new Floating Breakwater.

McNaught, W. No. 1,387.—On Simple and Compound Engines.

Meadows, J. M'C. No. 1,384.—Peat Fuel Machinery.

Pilbrow, J. No. 1,383.—On the Separate System of Sewering; and its first application to the district of Tottenham, Middlesex.

Prestwich, J. No. 1,403.—On the Origin of the Chesil Bank; and on the relation of the existing beaches to past geological changes independent of the present coast action.

Rapier, R. C. No. 1,393.—On the Fixed Signals of Railways.

Rendel, G. W. No. 1,385.—Gun-Carriages and Mechanical Appliances for working Heavy Ordnance.

Roff, G. L. No. 1,391.—The Extension of the South Jetty at Kustendjie, Turkey.

Scott, W. H. No. 1,381.—Notes on Mines fired near Bombay, 1866 to 1868.

Stone, C. No. 1,401.—The Implements employed, and the Stone Protection adopted, in the Reconstruction of the Bridges on the Delhi railway.

Vidler, M. No. 1,382.—Hints on the Failure of Brickwork.

Wilson, A. F. No. 1,396.—On the Destructive Distillation of Coal.

LIST OF DONORS TO THE LIBRARY.

FROM DECEMBER 1, 1873, TO NOVEMBER 30, 1874.

Academy of Sciences of Munich; Addy, J.; Admiralty; Agent General for Victoria; Aitken, R.; Allan, A.; American Academy of Arts and Sciences; American Institute of Mining Engineers; American Society of Civil Engineers; Amiot, M.; Anstie, J.; Archer, W. H.; Architectural Association; Association of Civil Engineers of Portugal; Astronomer Royal; Austrian Society of Civil Engineers.

Barnard, J. G.; Barr, General; Barry, E. M.; Barry, J. W.; Bauerman, H.; Baynes, J.; Beaudemoulin, L. A.; Bertin, E.; Binnie, A. R.; Bolton, Major F.; Boult, J.; Bow, R. H.; Bower, W.; Bramwell, F. J.; Brassey, T., M.P.; Brenan, G.; British Association for the Advancement of Science; British Association of Gas Managers; Brunel, H.; Brydges, C. J.; Bulkley, T. A.; Burgue, J. de; Burn R.

Campbell, J. R.; Campbell, W. D.; Canadian Government; Canadian Institute; Chabrier, E.; Chardanne, V.; Chemical Society; Cialdi, A.; Civil and Mechanical Engineers' Society; Clericetti; Cleveland Institution of Engineers; Coke, R. G.; Colladon, D.; Collignon, E.; Colonial Office; Cordery, J. G.; Corporation of London; Cotton, C. P.; Cunningham, Capt. A., R.E.

Dawnay, A. D.; Deacon, G. F.; Deas, J.; Delarge, F.; Dines, G. Eads, J. B.; East India Association; Evans, W. W.

Falconnet, Capt. G. P. de P., R.E.; Forge Committee of France; Fowler, A. M.; Fox, Head, and Co.; Francis, G.; Franklin Institute, Philadelphia; French Association for the Advancement of Science.

Gaudard, J.; Geological Society; Geological Survey of Canada; Gibbs, R.; Glasgow University; Glendining, A.; Gordon, R.; Gore, J. E.; Government of India; Government of Western Australia; Grantham, J.; Grantham, R. B.; Great Seal Patent Office; Greaves, C.; Greenhill, T. A.; Grover, J. W.; Gunesch, R.; Gzowski, C. S.

Hallauer, O.; Handyside, H.; Harrison, T. E.; Hartig, Dr. E.; Haughton, B.; Hayden, F. V.; Haywood, W.; Henwood, C.; Higginson, J. P.; Hildebrandt, A.; Homersham, S. C.; Hoseason, Capt. J. C., R.N.; Howard, W. F.; Hungarian Society of Engineers.

Industrial Society of Mulhausen; Institution of Architects and Engineers of Hanover; Institution of Engineers and Shipbuilders in Scotland; Institution of Mechanical Engineers; Institution of Naval Architects; Institution of Surveyors; Iron and Steel Institute.

Janson, M. A.; Johnson, S. A.

Keating, E.; Keystone Bridge Company; King's College, Nova Scotia; Knowles, Sir F. C., Bart.

Leloutre, M. G.; Letheby, Dr.; Liverpool Polytechnic Society; London Association of Foreman Engineers; Lovegrove, J.; Lucas, J.

Macmillan, Messrs.; Macrea, J.; Malézieux, E.; Manby, C.; Manchester Literary and Philosophical Society; Manchester Steam Users Association; Mast, G. C.; McAlpine, J. W.; McBean, S.; Meadows, J. McC.; Meteorological Office; Meteorological Society; Metropolitan Gas Referees; Midland Steam Boiler Inspection and Insurance Company; Millar, J.; Millar, J. M.; Muirhead, H. D.

National Boiler Insurance Company (Limited); New Zealand Government; Newbigging, F.; North, E. F.; North of England Institute of Mining and Mechanical Engineers; Nystrom, J. W.

Orsat, H.; Owens College, Manchester.

Parkes, W.; Patent Selenitic Cement Company; Phillips, J. A.;

Pimentel, J. G.; Pontzen, E.; Preece, W. H.; Price, W. H.; Proprietors of Annales Industrielles, Applied Science, Architect, Architect and Surveyor, Athenæum, Builder, Engineer, Engineering, Engineering and Mining Journal, Iron, Iron and Coal Trade Review, Iron Trade Circular, Journal of Gaslighting, London, Edinburgh, and Philosophical Magazine, Revista Minera, Telegraphic Journal, Universal Review of Mining.

Quinette-de-Rochemont, the Baron E. T.; Reade, T. M.; Registrar-General of Victoria; Révy, J. J.; Richardson, W. and W. C.; Ricketts, A.; Robertson, G.; Rosenbusch, E.; Royal Academy of Brussels; Royal Agricultural Society of England; Royal Artillery Institution; Royal Asiatic Society of Bengal; Royal Geographical Society; Royal Institute of British Architects; Royal Institution of Engineers of Holland; Royal Institution of Great Britain; Royal National Lifeboat Institution; Royal School of Engineers, Turin; Royal Scottish Society of Arts; Royal Society of Edinburgh; Royal Society of London; Royal Society of Victoria; Royal United Service Institution.

Salter, F.; Sassoon Mechanic Institute; School of Bridges and Roads of France; School of Military Engineering, Chatham; School of Mines of France; Scientific Industrial Society of Marseilles; Scott, M.; Scott, R. H.; Scott's Sewage Company; Shedd, J. H.; Siccama, H. T. H.; Simpson, Capt. E.; Smithsonian Institution; Smyth, R. B.; Society of Arts; Society of Civil Engineers of France; Society of Engineers; Society of Engineers and Architects of Saxony; Society of Telegraph Engineers; South Australian Government; South Wales Institute of Engineers; Spon, E. and F. N.; Statistical Society; Stevenson, D.; Stevenson, T.; Stone, C.; Swan, C. H.; Swettenham, J.; Symons, G. J.

Tate, J. S.; Thomason Civil Engineering College; Todd, L.; Trémaux, P.; Trevithick, F.; Trotman, J.; Tyler, Capt. H. W.; Tyrrel, Lieut-Col. F.

United States Corps of Engineers; United States Naval Observatory; United States War Department; University College, London; Unwin, W. C.

Van Nostrand, D.; Victorian Government.

Waldie, D.; Wardell, W. W.; Ware, C. E.; Waring, H. R.; Waterhouse, J.

Young, E. W.

The Subscriptions to the Library Fund were as follows :—

	£.	s.	d.
A. W. Brind	2	2	0
T. C. Ellis	2	2	0
Col. Hutchinson, R.E.	2	2	0
W. H. King	3	0	0
R. K. MacBride	1	1	0
William John Adamson Parker	1	1	0
John Arthur Phillips	3	3	0
Henry Prince	5	0	0
H. S. Collette Ree	1	1	0
J. C. Simpson	2	2	0
John Steell	3	3	0
Geo. Thompson	2	2	0
R. G. Underdown	5	5	0
Total as per Cash Statement	33	4	0

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Sect. II.—OTHER SELECTED PAPERS.

No. 1,412.—"Engineering in Sweden." By Christer Peter Sandberg, Assoc. Inst. C.E.[1]

There has now existed for ten years a Society of Engineers, "Ingeniörs Föreningens," in Sweden, with head-quarters at Stockholm, where meetings are held every quarter to discuss new schemes and engineering subjects. The society publishes a journal quarterly, the last number of which, for the second quarter of 1874, treats mainly of the Papers read and of the discussions that took place at the previous meeting. The journal gives a description and drawings of works executed in Sweden, of machinery, railways, bridges, architecture, heating, ventilation, water supply, &c. It likewise includes a *résumé* of foreign engineering works as well as of foreign engineering literature. The annual subscription of the members is about £1 1*s.*; but the journal may be bought by non-members for, say, 10*s.* per annum. A fresh administration is elected or re-elected every year. It consists of a president, vice-president, six members of council, and a secretary; the latter, who is also the editor of the journal and the treasurer, is paid a yearly salary. The society is in intimate connection with similar institutions in Norway and in Denmark, and is glad to exchange its publications with them, as well as with engineering associations outside Scandinavia. Due care is taken in the election of members, amongst whom are included nearly all the Royal Engineers of the kingdom.

Engineering in Sweden in old times principally consisted in canal-making between the numerous lakes and rivers. Foremost amongst these is the Great Gotha Canal, connecting Stockholm with Gothenburg by the lakes Wenern and Wettern. This canal is of surpassing magnitude and beauty, besides which it has proved an immense boon to industry.

The stagnation, however, of transport during winter necessitated the construction of railways; and although the Swedes have been

[1] The Author having been asked for particulars of the progress of Engineering in Sweden, communicated with the Swedish Society of Engineers, as well as with several Engineers in Sweden. No reply has yet been received, but he submits the following notes, rather than leave Sweden unrepresented in the accounts of foreign Engineering works.—C. P. S.

somewhat slow to commence railways, they have been by no means slow in covering the south or cultivated half of Sweden with a network of lines during the last twenty years. This, therefore, constitutes the principal engineering work of recent date. Next come the canals, the last executed, that by Baron Ericson, being called the Dalsland Canal, of which a description follows. There are, besides, waterworks, erected by Major Richert, the town engineer of Gothenburg, in Gothenburg, Norrköping, Upsala, and Lund; but, as a branch of engineering, the greatest activity is found in the iron trade, in laying out plant for the production of iron and steel by the Bessemer process from the famous ore smelted with charcoal.

I.—Railways.

To treat first of railways, the following is a *résumé* of their progress up to the end of 1874. There are 2,138 miles open for traffic, and 1,534 miles under construction, which will be completed in a few years, then making the considerable total of 3,672 miles. Bearing in mind the fact that Sweden is three times as large as England, with a population not exceeding that of London, there is a mile of railway actually open to every 1,800 inhabitants, which is just the same ratio as in England, leaving lines in course of construction out of account.

Railways open for Traffic.

	Miles.			Miles.	
State railways	897	Gauge 4 ft. 8½ inches, heavy construction.	Uddevalla - Wenersborg-Herrljunga	57	Narrow gauge.
Köping Hult	54		Borås-Herrljunga	26	
Gefle-Dala	57		Wickern-Möckeln	34	
Swedish Central	61		Karlshamn-Wislanda	48	
Halsberg - Motala - Mjölby	60		Pålsboda-Finspong	36	
Karlskrona Wexió	70		Mariestad-Moholm	11	
Kalmar Emmaboda	35		Wessman-Barken	11	
Landskrona-Helsingborg	37		Marma-Sandarna	7	
Ystad Eslöf	47		Sölvesborg-Kristianstad	18	
Kristianstad-Hessleholm	18	Gauge 4 ft. 8½ inches, light construction.	Hjo-Stenstorp	19	
Wexiö Alfvesta	11		Wadstena-Fogelstad	7	
Nora Karlskoga	40		Lidköping - Skara - Stenstorp	30	
Krylbo Norberg	12		Ulricehamn-Wartofta	23	
Nässjö Oscarshamn	90		Sundsvall Torpshammar	39	
Upsala Gefle	68		Sundry small lines	117	
Helsingborg Hessleholm	47		Total	483	
Malmö Ystad	40				
Sundry small lines	11				
Total	1,655				

LINES IN COURSE OF CONSTRUCTION.

	Miles.	
State railways	27	Gauge 4 feet 8½ inches, heavy construction.
Bergslagernas	366	
State railways	382	Gauge 4 feet 8½ inches, light construction.
Stockholm-Westerås	130	
Flen Oxelösund Eskilstuna	100	
Linköping Gamleby	70	
Östra Wermland	30	
Halmstad-Nässjö	97	
Landscrona Björnkulla	21	
Lund Trelleborg	26	
Nybro Säfsjöstrom	30	
Sala Tillberga	17	
Helsingborg Gothenburg	132	
Dalsland	40	
Sundry small lines	66	
Total	1,534	

These railways may be thus divided:—

	Miles.
Gauge 4 feet 8½ inches (heavy construction)	1,462
„ „ (light construction)	1,727
Narrow gauge	483
Total	3,672

These railways are divided into three classes, according to the manner of their construction and the work they have to do. First, there are at present open 1,069 miles of 4 feet 8½ inches gauge, of heavy construction, *i.e.*, with flange rails weighing 60 lbs. to 70 lbs. per yard, engines of about 33 tons, and an average speed of 30 miles per hour for express trains, stoppages included. It must, however, be stated that the speed is reduced in winter, on account of the severe climate, for safety as well as for economy in wear of permanent way and rolling stock. The chief examples of this class are the government lines, forming the greater portion, the most minute details of the construction of which may be found in the splendid work published by the Royal Administration, and of which a copy is in the library of the Institution.[1] The average cost of the government lines has been £7,000 per mile of single line, including rolling stock; the steepest gradients are 1 in 100,

[1] *Vide* "Royaume de Suède. Atlas des Constructions et du Matériel des Chemins de fer de l'état." Vol. i. Folio. Stockholm, 1870.

the curves are not below 1,000 feet radius, and very few are under 2,000 feet.

In the second class there are open 586 miles of the same gauge but of lighter construction, *i.e.*, the rails are from 40 lbs. to 60 lbs. per yard, the engines and rolling stock are lighter, but the gradients and curves are the same, with few exceptions; the speed attained on these lines is reduced to, say, an average of 23 miles per hour for the quickest trains. The average cost of this class has been about £4,000 per mile of single line, equipped with the necessary rolling stock.

Lastly, there are open 483 miles varying in gauge from 2½ feet to 4 feet, with rails weighing 20 lbs. to 45 lbs. per yard, and rolling stock in proportion. There is a greater variation in the curves and gradients, and the speed is diminished, say to 15 miles per hour, the average of the quickest trains. The cost of this class of line has ranged between £2,000 and £3,000 per mile of single line, rolling stock included.

As regards lines in course of construction the following points may be noticed. There are only in the first class about 393 miles, in the second class 1,141 miles, whilst the third class, or the narrow-gauge lines, are hardly worth mentioning. Of the 393 miles in the first class, the main part is a line for heavy traffic, viz., the Bergslagernas railway, from Gothenburg to Falun, with only a small mileage to complete the government system in the middle of the country. The great main-line system of the south and centre, which are the most populated districts, is now complete.

Of the 1,141 miles in the second class the principal section is the north government line, then the Stockholm Westerås railway, running into the mining districts, and about nine other lines which may be considered as feeders to the present main-line system, all of the full gauge with as heavy construction as their finances will allow. That the break of gauge has proved disadvantageous, is shown by the fact, that of the third or narrow-gauge class there are few examples in course of construction, and scarcely any are contemplated, except eight or ten unconnected local lines, chiefly for mineral traffic, and together about 150 miles in length.

The necessity of economy in the construction of railways strongly forced itself into notice ten years ago, and resulted in the narrow-gauge lines now made. In 1870, however, the debate in the Swedish parliament[1] ended in strong opposition to this

[1] *Vide* "Engineering," July 1860 and February 21, 1873.

break of gauge. This gained ground, so that when, in February 1873, the discussion arose at the Institution of Civil Engineers on the Indian gauge question, the general experience in Sweden was stated to be in favour of the standard gauge,[1] although several narrow-gauge lines were at the time under construction. Since then, the railway gauge question may be taken as decided in favour of the normal 4 feet 8½ inches, by the fact of but few narrow-gauge lines being projected, and by the adaptation of several narrow-gauge lines to the standard width.

The above-mentioned north main line, 382 miles long, extending from the Gefle line along the Baltic coast as far as Sundsvall, and then crossing Sweden to meet the Norwegian line from the frontier to Trondjem (Drontheim), was originally proposed to be of the 3 feet 6 inches gauge, to meet the Norway system, and to avoid break of gauge between the Baltic and the North Sea. It is now, however, to be constructed of the standard gauge, with rails weighing from 50 lbs. to 56 lbs. per yard, enabling the engines of 25 tons to 28 tons, originally ordered for the government main lines when the traffic was light, to be made use of, whilst these will be replaced by heavier ones for the south and central systems, where the increase of traffic requires it. The standard gauge being adhered to, the Norwegian line from Trondjem to the frontier is also to be of the 4 feet 8½ inches gauge. The present mileage of the 3 feet 6 inches gauge in Norway is only about 200 miles; and as this has in some instances proved to be inadequate in traffic capacity, it has been thought advisable to appoint a government commission to consider the question of gauge before extending that system. Moreover railway communication of several times that mileage is urgently needed between the north and the south, and there would be the inconvenience of break of gauge at Trondjem and at Christiania if the standard gauge were not adopted.[2]

In conclusion it should be said that the railway system of

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxv., pp. 337 and 520.

[2] "The Statesman's Year Book" for 1874 gives the mileage of Norwegian railways open for traffic as 586 miles, but there is included in this the line from Christiania to Stockholm, 350 miles, of which only 70 miles belong to Norway, thus reducing the Norwegian railways to 306 miles. An error is also made in stating the projected lines at 741 miles, as of the line from Trondjem to Sundsvall, 250 miles, only about 50 miles belong to Norway and 200 miles to Sweden, reducing the total to about 541 miles. In the same publication there is likewise an error regarding the cost of Swedish state railways, which is given at £131,725 per mile, instead of 131,725 rix-dollars, of which eighteen go to the pound sterling, or £7,318 per mile.

Sweden is of immense benefit to the trade of the country and of the world at large, for the value of the products, principally iron, corn, and timber, has tripled within the last twenty years. On the 18th of November, 1874, King Oscar II. opened the last link of the east main line, and referred in his speech to the credit belonging to the Swedish engineers, especially to the originator and constructor of the line, Baron Nils Ericson, whose death prevented him witnessing on that day the completion of this work. When, twenty years ago, government had to commence the construction of railways, under the management of Ericson as chief engineer, they were not expected to pay working expenses; now, in addition, they are paying 4 per cent. interest on the capital expended, and will, it is reckoned, in a short time yield a considerable surplus, besides the indirect gain to the country materially and socially. As nearly all the supplies of fixed and rolling stock for these railways have been obtained from England, their construction has likewise benefited this country.

II.—Canals.

Travellers in Sweden are generally under the impression, that there is more water in the country than is good for it. This is true, for hundreds of small lakes are drained every year, and valuable land reclaimed for agriculture. On the other hand, few countries, if any, in Europe possess a greater number of large lakes and rivers. If these are not all made navigable, it is by reason of the hard climate shutting them up for four months in the year.

However, but for the canals and inland water communication, Sweden would have been quicker to avail herself of railway communication. Before any railways were constructed, canals were extensively used for steamboat communication in all directions, as, for instance, across the country by the Gotha Canal through Lakes Wenern and Wettern, from Stockholm, to Gothenburg, a distance of about 280 miles; also to Jönköping, by Lake Wettern, in the centre of Sweden, 250 miles, then through Lakes Mälar and Hjelmare to Örebro, 140 miles; as well as for shorter distances in the north to Upsala and Smedjebacken. These, besides the coast navigation from the top of the Baltic at Haparanda down to Stockholm, and all round the coast to Gothenburg, supplied sufficient means of communication, had it not been for the winters. Although the inland navigation is suspended during that time of the year, transport is much facilitated by the use of sledges, a

horse being then able to draw double the load that it could do on a common road surface. Besides, the frost and snow open up a road everywhere; but when, occasionally, a mild winter produces little snow, communication is seriously impeded. The severity of the climate, for canals as well as for railways, is a grave consideration. The frost penetrates the ground 2 feet and more; and where drainage is not perfect, the expansion of the water in freezing disturbs the whole foundation, causing accidents when a thaw succeeds. Therefore, canals and roads require perfect drainage, deeper foundations than usual, and the very best material, such as granite, of which there is no scarcity in the country. As for docks and harbours, Sweden offers but little of interest, the rocky coast with the fjords affording natural harbours in most instances; and, as regards tide, a couple of feet, at the utmost, is the difference of range.

Commencing at the north, the project of a combined railway and canal communication across Sweden and Norway, from the top of the Baltic to the Arctic Ocean, has been lately entertained, to render accessible the immense iron mountain, "Gellivara"; indeed the canal is in course of execution by an English company. The project contemplates making the Lulea river navigable for about 50 miles, and constructing a railway from Norwik to Gellivara, about an equal distance. The Gellivara mountain is a vast store of iron ore, containing from 60 to 70 per cent. of metallic iron, which might thus be carried down the Baltic to England, although a long way round. As a cheaper and more direct route, a continuation of the railway is proposed from Gellivara in a northerly direction over the mountains to the Arctic Ocean at Ofoten fjord near Tromsöe, on the Norwegian coast, a port always free of ice. For, although this port is about 350 miles north of Lulea on the Baltic, it enjoys a much milder climate, owing to the presence of the Gulf Stream. Next to ironstone, it is calculated that the principal traffic will be in fish, chiefly cod, of which on the north coast there is an abundance. It is estimated that more than one million fish, weighing 10 lbs. each, and also salt and dried fish, together about 7,000 tons per annum,[1] as well as 400,000 tons of iron ore, may be offered for transport to the Baltic coast. As the locality is favourable, it is thought that the cost of construction, rolling stock and entire equipment included, will not exceed

[1] See Minutes of the Swedish Engineer Society, "Ingeniörs Föreningens." 1874, p. 42; Paper by Capt. Robert Schough, on a Railway from the Baltic to the Norwegian coast.

£1,000,000 sterling. It was the opinion of the Swedish Engineers, at the meeting on the 27th of February, 1874, that by the canalisation of the Lulea river a communication would be opened throughout the summer to the Baltic, and by railway transit to the Arctic Sea all the year, so that iron might be brought over the mountain Kölen to be smelted in England; and the hope was expressed that Government would undertake a thorough survey. So far as the difficulty of climate is concerned, the excessive frost and depth of snow may of course close the line for a short time during the winter, but it was considered that the traffic might be maintained during the greater part of the year without much difficulty.

Numbers of large rivers run parallel with the Lulea, southward to the Baltic, from the Kölen mountain chain, which separates Norway from Sweden. These rivers carry timber, in the spring flood, to the saw-mills, and some rivers are navigable for a considerable distance from the coast without needing extensive canalisation.

The canals are mainly in the centre and south, the principal being the Gotha, the Hjelmare, the Strömsholms, the Trollhätte, the Södertelge, the Eskilstuna, the Seffle, and the Dalslands. Of these the Gotha Canal deserves a special description, as being by far the most interesting, and the Dalsland, as being the latest executed.

The Gothia Canal.

This work was planned in 1716 by Swedenborg and Polheim, and was commenced by Charles XII.; but all the country's funds having been wasted by war, the enterprise was stopped for a long time, and it was only in 1800 that the first part, or the Trollhätte Canal, was opened. A few years later Count B. von Platen pursued the work, and called to his assistance the first President of The Institution of Civil Engineers, Thomas Telford, and in less than twenty days the whole line of route was surveyed and fixed.[1] The Gotha Canal Company was formed in 1810, with Count Platen as chairman. Shares were at once taken up for nearly a third of a million sterling, whilst Government supported the undertaking to an equal amount, making the total cost two-thirds of a million for the whole canal. Most of the work was, however,

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[1] *Vide* "Illustreradt Sverige," by Gustaf Thomée, p. 226; also "Life of Thomas Telford." 4to. Folio atlas of plates. London, 1838, pp. 159–162.

executed by soldiers, which lessened the outlay considerably. In 1832 the canal was completed across Sweden, from Stockholm to Gothenburg. A length of 56 miles was of the following dimensions:—

	Feet.
Width at the bottom	48
Width at the surface	90
Depth	10

There are fifty-eight locks, 246 feet long and 24 feet broad, thirty road bridges, and several culverts, aqueducts, basins, and repairing docks. The highest point is 308 feet above the sea level, at a little lake called Wiken, from which there is a descent of 163 feet down to Lake Wenern, the largest in Sweden, having an area of 2,080 square miles. At the outflow of the lake at Wenersborg, the Carlsgraf Canal, with two locks and a length of 12,000 feet, avoids the first waterfall into the river Gotha, where, however, navigation is soon interrupted by the well-known falls of Trollhätte, 112 feet high, but divided into four different falls. The canal is here very interesting, being for the most part blasted out of the granite rock by the side of the waterfalls.

Long before the Gotha Canal was ready, Lake Wenern was in connection with the west coast through eight small locks, each 20 feet broad and 3½ feet deep, at Trollhätte; but in connection with the Gotha Canal, Nils Ericson built a set of twelve new locks, 5 feet deep, and formed a separate company, called the New Trollhätte Canal Company. After the completion of the new locks the navigation was accessible to larger vessels, and it was even proposed to open a communication direct between St. Petersburg and England through the Gotha Canal, but the boats were found to be too small for the rough passage across the North Sea. About five thousand sailing vessels and two thousand steamers pass through this canal yearly, paying dues amounting to £20,000 for the Trollhätte Canal only. At the Gotha Canal the traffic is less, being two thousand five hundred sailing vessels and one thousand steamers, and the dues are about £10,000.

The Dalsland Canal.

The eastern spurs of the high range dividing Norway from Sweden run in the south through the small province of Dalsland, towards Lake Wenern, and form numerous valleys, which descend more or less abruptly to the shore, and serve as channels for many torrents from the mountain ridges. There are often considerable

falls, which supply a vast motive power to works of various kinds, chiefly bar-iron forges and saw-mills. There was one serious drawback to this industry. Lake Wenern afforded the only means of communication between Dalsland and the outer world; and to reach that lake from the various works a long and costly land transport was the sole resource. This became more and more an obstacle as increased facilities were developed in other parts of the world.

Hence, forty years ago, the question of utilising the Dalsland watercourses as a means of transport was broached, and this was accomplished in the year 1868. Along the Norwegian frontier, northward, in the province of Wermland, there is a lake, the Stora Lee, 20 miles long with an extreme width of 3 miles, which joins Lake Wenern by a watercourse having eleven continually descending basins, together constituting a fall of 200 feet. At the northern extremity of the Stora Lee are the Toksfors works. At a distance of 12 miles southward, where there is a fall of 28 feet, are the ironworks of Lennartsfors. At this point the Stora Lee is joined by Lake Leelângen; and lower down at the junction with Lax Lake, motive power is supplied by a fall to the Billingsfors works. Farther on, towards Lake Wenern, there are the Gustafsfors ironworks and the Skapfors saw-mills, where falls occur, the highest one being 30 feet at Upperud ironworks.

The Dalsland Canal Share Company having been formed, with the Governor of the Province, Count Sparre, as President, the directors, in 1864, succeeded in engaging the assistance of the late Baron Nils Ericson, Colonel of Engineers. His plan to some extent varied from former projects, and comprised the following main conditions: the construction of a canal at Hofverud, near Upperud, instead of a railway, so as to avoid unloading and reloading; a route from Lax Lake, past the Billingsfors works, to Leelângen; the adoption of the same dimensions for the whole length of the canal from Upperud to Stora Lee, viz., a depth of 5½ feet, a width of 13 feet at the bottom, and a length of 100 feet between the lock gates; and an increase in the number of locks between Lake Wenern and Stora Lee to twenty-five, instead of fifteen as proposed.

The contract for constructing the canal according to this plan, including excavations round the fall at Hofverud, and an aqueduct over the stream at that place, was taken at about £76,000 sterling, raised chiefly by shares, and to some extent by state subventions. It was stipulated that the dimensions of the canal should be such that vessels of 75 feet in length, 13 feet beam, and drawing 5 feet of

water, should be able to navigate it. Consequently the locks were mainly of the following dimensions:—

	Ft.	ins.
Minimum length between the gates	100	0
,, width in the flood gate	14	0
,, depth of water on the sill	5	2
,, width of the sill	6	0
,, height of the gate wall over the sill	6	7
,, length of the gate wall	7	0
Radius of the sill and of the lift wall	16	0
Length of the gate recess	17	0
Radius ,, ,,	50	0
Slope of the lock-chamber sides, 5 to 1		
Versed sine of the exterior of the inner wall	2	0
,, ,, ,, outer ,,	3	0

The gate walls and recesses were all constructed with Wargö cement. The sides of the lock chambers are of masonry in cement, supported by an earthen embankment. The gates are single, and have wooden bolts; the sills are formed of wooden beams, 10 inches by 12 inches. Timber drawbridges are employed throughout, placed in front of a lock immediately before the recess, or entrance.

The canal is of the following dimensions:—

	Ft.	ins.
Minimum width at the bottom	13	0
,, depth	5	6
,, height of the bank above water level	2	0
,, width of the bank at top	8	0
,, ,, towing path	5	0
,, slope of the banks, 1 to $1\frac{1}{2}$		

At the waterfalls of Hofverud, the most interesting point of this canal, the rock on one side is almost perpendicular for 150 feet, while the other side of the stream is occupied by the ironworks of Hofverud. For this reason Ericson constructed an iron aqueduct over the fall of 110 feet span. This aqueduct has the form of an open box. The two sides for carrying the weight are wrought-iron bow girders, 10 feet deep at the middle and $6\frac{1}{2}$ feet at the ends, of English iron plate, $\frac{1}{4}$ inch thick. The bottom and top flanges are $\frac{1}{2}$ inch and $\frac{5}{8}$ inch thick respectively, formed of three layers of plates bolted together. The top flange serves as a pathway as well. The aqueduct joins the canal at both ends, and is supported at one end on turned rollers resting on a bed-plate, so as to allow free contraction and expansion, the other end being fixed. The aqueduct has a depth of $5\frac{1}{2}$ feet of water, and weighs when full 200 tons, but with a loaded vessel the structure is calculated to carry 300 tons. This canal has now been open for traffic for five

years, and has proved to be of thoroughly sound and good workmanship. There are hopes that in course of time it will turn out as successful financially to the shareholders, as it has already been beneficial to the province of Dalsland.

III.—Iron-making and Mining.

Sweden and England have been connected from olden times in this branch of industry, through the one supplying the other with raw material in the form of bar iron for cast-steel production and steel manufactures of the finest description.

The purity of the ores, as well as the use of charcoal for smelting, has given the superiority to the Swedish iron; while the good quality of the coal and coke, and the abundance of other materials, such as sandstone, fire-clay, &c., have placed the manufacture into finished articles chiefly in Sheffield and some other districts in England similarly situated.

In early days the exportation from Sweden was limited to bar iron, the export of pig iron and of iron ore being forbidden, and a duty was levied on imported iron and machinery. Since the establishment of free trade on both sides a different state of things has arisen, and now, not only is bar iron imported, but also pig iron and iron ore; although there is very little of the latter kind, partly because Spanish ore competes with it, and partly because railway communication from the coast has not yet obtained full access to the mining districts in the interior. On the other hand, the importation of English iron, formerly very limited, has so increased, that in the year 1873, Sweden imported iron, chiefly railway materials, to a value equalling that of the export, viz., £1,000,000 nearly.

This exchange is very remarkable. At first sight it seems strange that Sweden should export so large a quantity of iron to England, and import so much in return, instead of supplying her own wants. The explanation, however, consists in the fact, that the iron exported, which is smelted with charcoal, is far too good and costly a material for the manufacture of ordinary iron and railway bars—English iron being good enough for the purpose—and the absence of coal has hitherto precluded smelting in any other way than by charcoal. Again, English ores smelted with coke and coal do not afford a sufficiently pure raw material for the higher qualities of iron and steel.

Both countries have all along aimed at becoming independent of each other in iron and steel making; and more especially is this

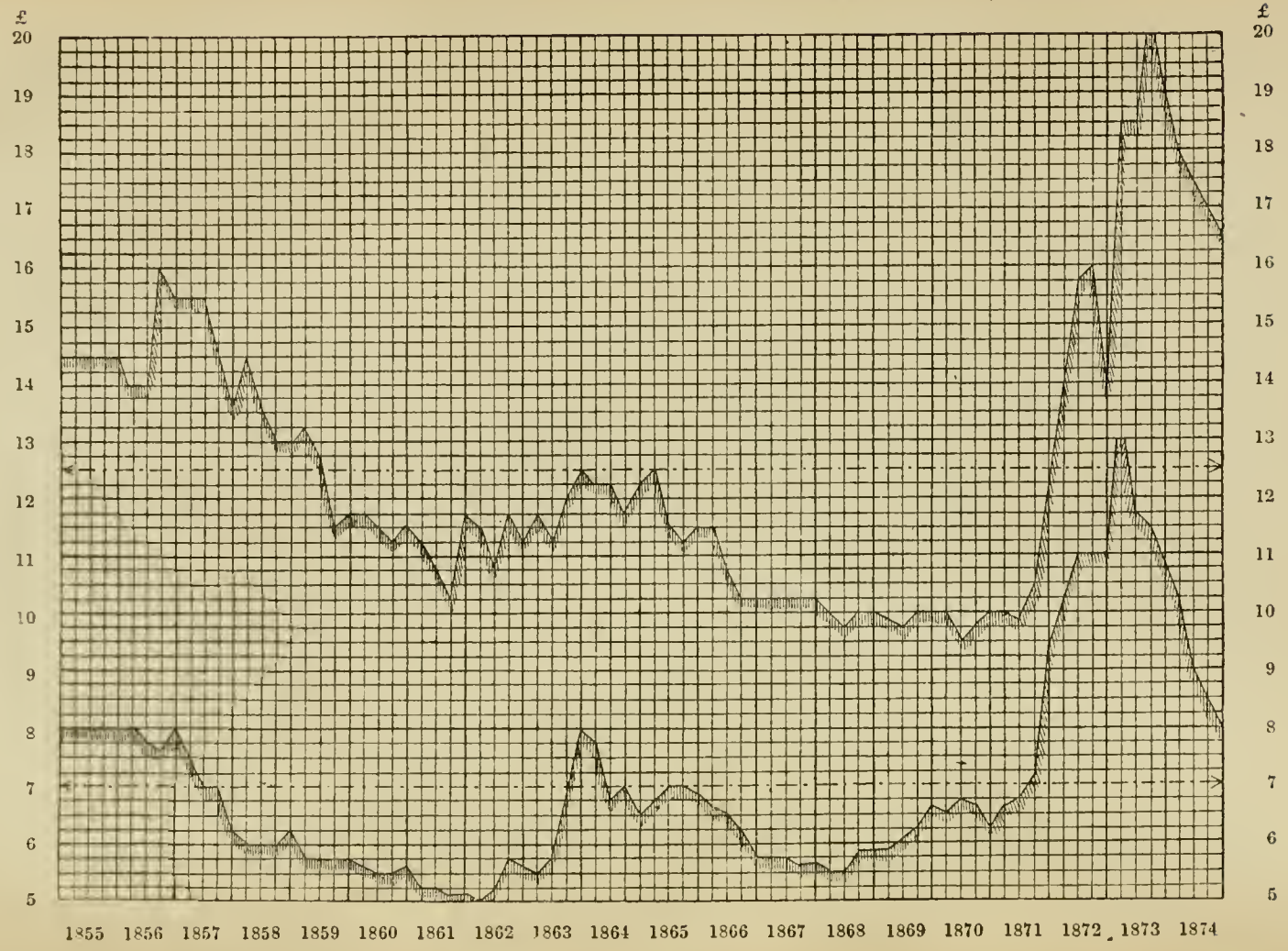
the case at present. Sweden, by opening up railway communication in the mining districts, seeks to establish means of transport for English coke and coal to the seat of iron production, with the ultimate end of a far more extended home manufacture. At the same time search is being made for coal, and not altogether without success; for in the south coal has lately been discovered in several places, but the quality is not equal to English coal, and moreover the deposits are, unfortunately, at a distance of about 300 miles from the iron districts. The great aim, on that side, is to establish larger ironworks for the manufacture of machinery and of railway plant, for home use at least, if not for exportation.

In England, on the other hand, it is sought, by the importation of ores from Spain, as well as by opening up all the superior sources of the country, such as the hæmatite mines, to be independent of Swedish raw material. Further, by improvements in manufacture, by new processes, such as Bessemer's and Siemens', as well as by mechanical puddling, it is attempted to obtain a high quality of iron even from an inferior raw material. Whatever may happen in the future, the fact remains that, during the past twenty years, the value of the exchanged metal has constantly increased, instead of diminished. As the relative market price is the best illustration of the value of different metals, a diagram has been prepared of the comparative prices for the last twenty years of Swedish and English merchant bar iron. (See page 204.) This diagram refers to ordinary qualities; such extra qualities as, for instance, the Dannemora in Sweden, and the Lowmoor in England, are not taken into account.

It will be seen that, during the last twenty years, the average price of English iron has been £7 per ton, that of Swedish iron £12 10*s.* per ton. The high price obtained for Swedish iron has amply paid for the exchange before mentioned. Had the native iron been used for rail-making it would have been too good, or rather too costly, inasmuch as the limited traffic at the commencement of railway working is such that even with English iron rails, when made to specification and under strict inspection, an endurance of fifteen to twenty years may be safely calculated on.

Besides the comparison between the Swedish and English iron trade, the diagram shows the fluctuation in price of iron generally. Such sudden rises as during 1872 and 1873 have been unprecedented of late, and had, no doubt, their principal cause in the changes brought about, materially and socially, by the Franco-German war. These causes having ceased to operate, and America, the greatest British customer, having withdrawn nearly all her

AVERAGE PRICES OF SWEDISH AND ENGLISH IRON FOR TWENTY YEARS, 1855-74.



Average price of Swedish iron, £12 10s. per ton
" " English " £7 " } Net cash F.O.B. English port.

orders, partly from the effect of the financial panic, partly from increased home manufacture, the late sudden fall is equally accounted for. The fact that prices, both of iron and of steel, are at a normal rate again, or thereabouts, is important to engineers, who may now make their estimates for railways, water and gas-works, &c.—for all of which the prices of iron and steel form a vital item—on ordinary or normal bases.

The iron-making of Sweden may be divided into three operations:—

1st. Mining and charcoal-burning.

2nd. The calcining and smelting of the ore into pig iron.

3rd. The conversion of the pig iron into wrought iron and steel for the market.

First, concerning mining operations, the geological formation of the kingdom is chiefly primary rock; and magnetic ores in layers are found in the gneiss and granite. The ore is blasted either by powder or dynamite, and, although hand labour for boring is generally used, boring machines are being gradually introduced with great advantage, as the rock is often very hard. Boring machines are also used for sinking trial shafts both for iron and other ores, as well as for coal in the south. Engineering skill is wanted for the actual working of the mine, and for lifting the ore and spoil. Water power is mainly employed, often carried to the pit from long distances, yet so well economised that from 70 to 80 per cent. of natural force is utilised by large overfall waterwheels. With the exception of Gellivara at the extreme north, the mines are mostly in the heart of the country, say 100 miles to 200 miles from the coast, and the seams are of various dimensions—up to 100 feet and 150 feet thick. It should be stated that, in order to stimulate discoveries of mines generally, the law grants one-half of the proprietorship thereof to the finder, the remaining moiety to the ground landlord. As regards coal, this provision has of late caused considerable embarrassment to the landowner, so that a bill has been passed to prevent further concessions for the present to the searchers for coal mines. At the last meeting of the Iron and Steel Institute, at Barrow, Mr. Charles Smith read a Paper "On the Iron Ores of Sweden,"[1] which contained much information as to the different mines, their names and locality.

Charcoal-burning takes place in the forests, the tops and branches

[1] *Vide* "The Engineer," Sept. 11, 1874, pp. 198, 199.

of the trees being used for this purpose, the lower part of the trunk being cut into planks for the saw-mills. The wood is piled together, either vertically or horizontally, and covered with sand and coal-dust, which is kept damp during the whole of the burning or carbonising process. When this is completed, say in a week or two, the fire is damped out, and the pile is left till snow falls and the lakes freeze so as to enable roads to be formed anywhere. The charcoal and ore are then carried in sledges to the blast furnaces. A detailed description of charcoal-burning in Sweden is given in Dr. Percy's "Metallurgy." [1]

The iron ores chiefly consist of oxide and peroxide, yielding from 40 to 70 per cent. of pig iron. The rock, which is generally more or less in admixture, consists of silica, alumina, lime, magnesia, and manganese, with but little or no phosphorus or sulphur, and from the absence of these ingredients arises its high value. The constituents of the charge of the furnace are regulated so as to afford an easily smelted slag, of more or less basic consistence according to the quality of the pig to be produced; thus, iron ores containing much lime are mixed with those containing much silica. Generally, however, the silicious ores are the most prevalent, and want of lime in the ore itself must often be supplied by the admixture of that substance. The calcining or burning process consists in heating the ore to red-heat, or as near to melting point as possible without running the pieces into one lump. This is done in furnaces which are heated by the waste gas from the blast furnace, the gas being let in about the middle of the height, and there lighted after having been conducted to that point in an iron pipe.

The object of this preliminary calcining is partly to prepare the ore for reduction, or for the more easy separation of its oxygen, and partly to burn away the sulphur, if such should in small degree be present. This process is not absolutely necessary for other ores, and in fact is seldom used in England, but for the economical reduction of Swedish ores it is indispensable. After calcination the ore is crushed to the size of walnuts, and carried to the top of the blast furnace, where it is mixed with other ores and charged with lime if necessary.

The charcoal blast furnaces are described by Dr. Percy, as well as the whole process of smelting; their chief difference from the English coke furnaces consists in much smaller dimensions,

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[1] *Vide* "Metallurgy. By John Percy, M.D., F.R.S. Fuel, etc." 8vo. London, 1861, pp. 107–136.

with a corresponding deficiency in production, 40 to 50 tons being a good weekly average. The reason why charcoal furnaces are not made bigger, or of greater productive capacity, is partly owing to charcoal being more easily crushed than coke, and partly because with 50 tons production per week the consumption of charcoal is so great and the supply so limited, except by bringing it from long distances, that even one furnace cannot be kept going all the year round; indeed, three to four months in blast is considered fair work. This accounts for the furnaces being spread singly all over the country to the number of two hundred or three hundred, with a total production of about that of one or two of the largest ironworks in England, or 330,000 tons for 1872 from 700,000 tons of ore brought up. It is therefore evident that what is wanting in quantity must be made up in the quality of the pig iron produced, and so it is; for the price of Swedish charcoal pig iron may be taken to be 60 per cent. above the price of ordinary English pig iron. It is used principally for conversion in the charcoal hearth to wrought iron, also of late largely in the Bessemer process, as well as in puddling for superior production; only small quantities being employed for foundry purposes.

The ordinary method of converting pig iron into wrought iron is the so-called "Lancashire" method,[1] now abandoned in that country, but still existing in some Welsh tin-plate works. It was introduced into Sweden by Mr. G. Ekman, who also brought out a welding gas furnace[2] to heat the blooms, obtained in the charcoal Lancashire hearth, for rolling or hammering into bars.

At an early stage of the experiments with the Bessemer process, Mr. Göranson, of Sandwiken's works, near Gefle, took up the process, and considerably contributed to its success by adapting to it the Swedish raw material. Although for many years financially disadvantageous both to Mr. Göranson and to Mr. Bessemer, it is now working with great profit. Notwithstanding this there are but seven or eight Bessemer works in Sweden, the reason being the difficulty of concentrating the produce in one place, as before stated. However, the increased facilities of transport afforded by railways will enable larger accumulations of raw material to be made than formerly, and gradually establishments will be erected on a more modern scale for the manufacture of finished articles, such as axles and wheels, tires, plates, and even rails,

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[1] *Vide* "Metallurgy. By John Percy, M.D., F.R.S. Iron and Steel." 8vo. London, 1864, p. 591.

[2] *Ibid.*, p. 716.

by the Bessemer process, as Swedish pig iron is better adapted for this than for the puddling process. One of the latest established works in Sweden for the manufacture of iron and steel by the Bessemer process is situated at a junction of railways and water communication, and here it is proposed to erect as many as four blast furnaces. The engineering work consists in adapting the river so as to obtain a water power of at least 300 HP., and in the erection of machinery and buildings as follows [1] :—

	£.
Canal and water power	22,000
Railways	4,000
Charcoal storehouse, two gas kilns, two blast furnaces, two Bessemer converters, with blowing machines, turbines, and houses for the same, complete	60,000
Foundry and mechanical workshop	5,000
Brick-making shop and saw-mills	2,000
Storehouses, labourers' cottages, offices, &c.	7,000
Total	100,000

The blast furnaces are 55 feet high, 4 feet internal diameter at the bottom, 9 feet at the bosh, and 5½ feet at the top. Each has a capacity of 2,670 cubic feet. The apparatus for heating the blast has 900 square feet of surface. From the blast furnace the pig iron is carried, in a melted state, to the Bessemer converter by rail, to save re-melting. The converters, which hold 4 tons, the cranes, hydraulic and mechanical arrangements are of the ordinary English type. To the above cost should be added the purchase of the ground, as well as the expense of the water supply, and sufficient mines to supply two furnaces, in all say £20,000, thus raising the total cost of the establishment and construction of a Bessemer works to £120,000 for the production of steel ingots to the amount of from 4,000 tons to 5,000 tons yearly. Next come the forge and the mill, the construction and cost of which depend upon what is to be made from these ingots, whether rails, axles and shafts, tires and wheels, or plates and bars. Of such mills several are in course of erection, but none are yet completed so as to afford reliable information or experience.

From this it may be seen that Bessemer works of the above description are, for Swedish ironmasters, rather a large under-

[1] *Vide* Minutes of the Swedish Engineer Society, "Ingeniörs Föreningens Förhandlingar," 1874, p. 73; Paper by Professor C. A. Ångström on Bångbro Ironworks.

taking, and would require the association of a good many small masters, for which they are often little inclined. This accounts for the slow adoption of the Bessemer process in Sweden, notwithstanding there is no country where the raw material is better suited for it. In this respect the Siemens process is more suitable, as being adapted for smaller production, and entailing less outlay for its introduction. Several establishments are in course of construction for this process, but they are not yet completed. This applies to the Siemens smelting process of wrought iron and pig iron into steel in the reverberatory gas furnace; as the direct process by reducing ore and making iron and steel would not be facilitated in Sweden, where the ores are more difficult to reduce than the hæmatites of England.

The puddling is chiefly carried on at Motala, where also Danks' mechanical puddling has been tried. At the Motala works there is a splendid establishment for steamboat building, and nearly all the numerous steamboats for the inland and coast traffic have been built there; sometimes, by these vessels running aground, or coming into collision, excellent proofs of the ductility of the plates are afforded; there is very seldom a breakage, but only distortion of form, which is easily repaired without much loss. The Swedish Navy is likewise supplied with vessels from this establishment.

In round figures, the annual pig iron production of Sweden is 300,000 tons. Out of this quantity 180,000 tons are made into bars, 8,000 tons into Bessemer steel, 6,000 tons into plates, 6,000 tons into nails, 3,000 tons into rails, and 10,000 tons into manufacturing, agricultural and other implements. This quantity is produced by five thousand miners, three thousand ironworkers for the blast furnaces, six thousand at the forges, six thousand at the foundries and manufactories, or say twenty thousand in all, which is no small proportion out of a total population of 4,000,000. The calculated value of the iron mines is about £1,000,000 sterling, that of the blast furnaces, foundries, and factories £1,000,000, and that of the forges and mills also £1,000,000; say £3,000,000 in all for the Swedish iron mines and works, of course fluctuating in proportion to profit made in the trade.[1]

Besides a separate division of the Board of Trade for mining and metallurgy, there is in Sweden an institution of which there is no parallel in England, viz., the "Jernkontor," or iron office. The old ironmasters of Sweden subscribed to establish a

[1] *Vide* "Statistisk Handbok." E. Fåhrœus. Stockholm, 1872, p. 307.

banking institution, with the object of supporting trade in bad times, by granting loans to the iron proprietors at low rates, on stocks of iron which could not at the time be realised advantageously. The funds for this Institution were and are now obtained by levying a small rate on production, and the total funded capital is about £300,000. The iron trade of Sweden is assisted in addition by a considerable staff of engineers, mining, metallurgical, and mechanical, mainly supported by the Jernkontor. The country is divided into mining districts, with a director and engineer for each, and a few articled pupils, all receiving a yearly salary from the Jernkontor, and allowed to charge the ironmaster a small settled fee when employed in the construction of new works, or in the introduction of new processes. The staff have received a course of scientific and practical education at the government School of Mines, and they are often sent to foreign countries, in order to keep the ironmasters informed of what is going on abroad. For the last forty or fifty years the "Jernkontor" has published a journal, called the "Jernkontorets Annaler," containing mainly the annual reports of each of these employés. It is now ably edited by Professor Richard Åkerman, of the Royal School of Mines in Stockholm, and is sent gratuitously to all the ironmasters in Sweden, but is obtainable by the public at a low cost. The Jernkontor is governed by a president, vice-president, and ten councillors, who are elected every third year; their meetings are held every quarter in Stockholm, where the permanent secretary and treasurer conduct business in the intervals between the meetings.

It would be unjust to finish this description of Swedish engineering without acknowledging that the credit mainly belongs to the Corps of Royal Engineers for the construction both of the canals and of the railways. The country is divided into districts in respect of road and water communications, and each district is provided with officers to survey and execute public and private works. Members of the Corps of Royal Engineers are previously educated at the Government School of Civil and Military Engineers at Marieberg, near Stockholm, and afterwards have to execute both private and public works as well as inspect them before they are opened. A yearly report is submitted to Parliament of work done in each district. This formerly consisted in canal-making, drainage of lakes, building of harbours and docks, and new roads, for which Government generally defrays part of the cost.

Railways have advanced to such an extent in Sweden, that the Corps has of late been too much occupied to give a detailed de-

scription of work done; the reports have in consequence been complained of as short and uninstructive. There being no special department of Government for public works, railways, canals, and mining engineering come under the control of the Minister of the Interior. With the increase in construction of railways and public works generally, there is thought to be a necessity for a Department of Public Works, similar to like branches of the Government in other countries, to regulate the construction of new lines as well as the working of those open, to promote industry, and to serve as a guarantee for public safety. Should such a department be established, nothing would be of greater assistance to the engineering profession in that country, and particularly to the Civil Engineers, who may now be considered as a body without a chief.

No. 1,401.—" The Implements employed, and the Stone Protection adopted, in the Reconstruction of the Bridges on the Delhi Railway." By CHARLES STONE, M. Inst. C.E.

IN 1867, when in charge, for the Company, of the Jumna bridge works, Delhi Railway, the Author commenced making notes with a view to write an account of the system of well-sinking then in progress. Finding, however, Mr. Imrie Bell, M. Inst. C.E., who represented the contractors at that time, and who was daily employed in superintending the practical working, similarly engaged, the idea was given up, in the belief that his Paper would be the more valuable one.[1] Since then the unusually heavy floods of 1871–2 have caused serious disasters to the bridges, scouring out many of the well piers and of the wells of wing walls, although the former were sunk to depths of from 40 feet to 43 feet, and the latter to depths varying from 26 feet to 43 feet, below low water, indicating that those depths were insufficient, unless the foundations were protected by beds of stone, to prevent or reduce the scour. This has been successfully carried out, new well piers have been sunk to an increased depth, and protected with stone, and training bunds have been put in for conserving the rivers above bridge for the protection of the abutments.

The Author now desires to supplement Mr. Bell's Paper, with an account of the various implements used in the reconstruction works carried out under his supervision at the Sutlej, Beas, and Jumna rivers, and with a description of the system of stone protection adopted at all large rivers and streams subject to floods, crossed by the Delhi railway, as well as of the training banks put in for preserving the channels above bridge,—a system which, from the experience gained, is being universally followed by the Engineers of the State railways.

It was decided to sink the new piers for the bridges over the rivers Beas and Sutlej to a depth of 70 feet, if possible, below low water, and to increase the diameter from 12 feet 6 inches to 15 feet; but to reduce that diameter to 12 feet 6 inches at low-water level, so as to correspond with the other piers of the bridge. The first well curbs, of 12 feet 6 inches diameter, were of iron; those

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 325.

used in the reconstruction works were of wood, in sections or rings, so as to break joint, and dowelled together.

The system of sinking with the jham and sand pump has already been described by Mr. Bell. From the increased diameter of the cylinders, and the increased depth, the sand pump alone was found insufficient for the purposes, owing to the stiff clay and conglomerate met with at from 30 feet to 35 feet below low water. Accordingly the sand pump has been superseded, to a considerable extent, by Bull's dredger[1] (Plate 12, Figs. 1 to 4), used in sinking the new wells of the above bridges. The dredger is lowered into the well by a crab and tackle working over a pulley fixed to a gallows or sheer-legs, erected on a stage at the top of the well. Before lowering, the clip or double pin (Fig. 4) is inserted into holes in the two segments (Fig. 2); this keeps the dredger open until it reaches the bottom of the well, when the clip is withdrawn by means of a stout cord. The lowering chain, attached to the chains working in guides and small rollers at the four corners of the dredger, is then pulled up slightly, agitated, and lowered by coolies. By these means the jaws of the dredger are gradually drawn together, scooping up the sand or loose material. The number of times the chain is so pulled depends upon the material to be dredged. With loose soil the jaws soon meet, when the dredger is drawn up, opened on the staging, and the materials fall out; the clip is then again inserted, and the operation repeated. In sand, the time occupied for each operation of lowering, dredging, and lifting averages five or six minutes; the depth in this case being, from the top of the staging to low water 25 feet, from low water to the bottom of the curb 46 feet, the depth of hole dredged below the curb 12 feet, or a total of 83 feet. With the sand pump a corresponding operation would take more time, as the four cotters have to be driven out when the pump is dropped on to the staging, the pump raised to leave the bottom clear to remove the sand, and then lowered and re-keyed. So long as the material is sand the dredger is effective; but, like the pump, it can only be lowered into the centre of the well, and the result is that, in stiff material, the dredger works out a hole in the form of an inverted cone, and the quantity dredged at each operation is small.

In the stiff clay and conglomerate met with at the Sutlej at a depth of about 35 feet, the progress of sinking was exceedingly

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[1] An account of this and of other excavating apparatus is contained in "Professional Papers on Indian Engineering," 2nd series, vols. i., ii., and iii. *passim*.

slow. The Author then tried a jumper, composed of rails fished together for the required lengths, the end of the lower length being chiselled to an edge. This jumper was raised by a crab engine or by coolies to a height of 8 feet or 10 feet, then suddenly let go, when the jumper became imbedded deeply in the clay. The operation was repeated until a sufficient quantity had been loosened, when the dredger was used, bringing up masses weighing from 20 lbs. to 85 lbs. This combined system, of the heavy chiselled jumper and the dredger, has been found the most suitable for great depths and stiff material. One advantage of the chiselled jumper is that, when raised to the required height, it can be 'guyed' over and dropped at any point within the well. But after excavating, by these means, to a depth of 16 feet below the bottom of the curb, notwithstanding the wells were loaded with rails and other iron material to the extent of from 700 tons to 800 tons, the wells would still hang. Divers were then sent down to excavate under the curb; and after dredging out the stuff so cut away, and exhausting the water to within 8 feet of the bottom, the wells seldom sank more than 1 inch at a time. In the wells recently sunk at the Sutlej, the soil was so dense that an average depth of only 2 feet 10 inches was attained for each well, after working in the way above described for three months.

The wells were filled with concrete by ordinary skips. To accomplish this, to build up the piers from low-water level, and to lay the girders before the floods came on, it was necessary to suspend operations at a depth of 47 feet below low water. But as probings showed that there was a stiff bed of clay and conglomerate for at least 15 feet below the bottom of the curb, and as the wells were protected by 20,000 cubic feet of heavy blocks of stone thrown in round them, it was believed they would not be injured by scour.

An excavator for deep well foundations has been introduced by Mr. R. J. Ives, a sub-engineer in the Public Works Department, which he believes will supersede sand pumps and dredgers, at all events for stiff clay. Figs. 5, 6, and 7 (Plate 12) represent the tool as adapted for clay, Figs. 8 and 9 as applied for sand. The mode of working is as follows: The excavator lock, at the back, is first pushed into place, a light line being attached to the lock, as shown. The blade is now open or vertical with the monkey guide rod, in which position the excavator is lowered to the bottom of the well, where the apparatus is kept upright by the lowering-chain being held slightly taut. The monkey is now worked up and down the centre guide rod, by the line attached to

it, leading over a pulley fixed on a staging on the top of the well. The monkey, being allowed to fall by its own weight, gives a sharp blow to the head of the excavator, and drives the blade into the ground at each blow. After a sufficient number of blows, the locking gear is pulled, which draws out the locking-bolt and releases the blade from its vertical position; when this has been done, the lifting-chain is hauled by the crab, and the blade dragged out of the ground with its load, in a position at right angles with the monkey guide rod. Continued hauling on the lifting-chain brings the whole to the top of the well, where the material so excavated is tipped. The locking gear is again pushed into place, and the apparatus lowered into the well for another operation.

Several objections presented themselves in the use of this excavator. It should assume, at starting, a perpendicular position to give due effect to the monkey. A certain amount of slack is necessary at each blow, and it was found that after a few strokes the apparatus was thrown over to an angle of 30° or 40°, and was practically useless. Again, the excavator could not be lowered, to work at any great depth, otherwise than in the centre of the well; the result was that it dropped into the same place successively; whereas an implement is required that will operate about the whole of the inner diameter of the well. A further drawback was the continual derangement, by the jarring, from the repeated blows of the monkey. It was therefore abandoned for the more effectual and cheaper implement, the chiselled-rail jumper previously described.

Figs. 1 and 2 (Plate 13) represent the systems of stone protection carried out at the bridge over the Jumna and on the east bank of the river. The bridge has twenty-four spans of 110 feet, the girders of the superstructure resting on well piers of 12 feet 6 inches diameter. The abutments are built on wells of the same diameter, sunk, like the well piers, 43 feet 6 inches below low-water level. The curved portion of the wing wall, on the up-stream side, was built on seven 10-feet wells, sunk from 43 feet 6 inches to 32 feet 6 inches, and the straight portion on twenty-six 7-feet wells, sunk from 28 feet to 26 feet 6 inches, in both cases below low water. The down-stream wing wall was founded on seven 10-feet, and fifteen 7-feet wells, sunk to depths corresponding with the up-stream wells. In the floods of 1871, which were higher than any on record since the commencement of the first surveys in 1861, a powerful current set against the east bank of the river,

above the bridge, which at this time extended nearly three spans forward from the face of the abutment. From the nature of the soil, the erosion was very rapid back to the abutment, so that the current soon began to encroach on the high ground in front of the wing wall, and eventually scoured out the wells of the wing wall on the up-stream side; fortunately the abutment wells escaped. After the floods subsided, a careful inspection was made, when it was decided, instead of sinking new wells, to try the effect of heavy blocks of stone in trenches 10 feet wide, and as deep below low water as ordinary excavations would permit. This was done at the foot of the slope of the embankment, extending back ½ mile from the abutment. An additional work in advance of this, and similarly trenched, was also put in for the more immediate protection of the abutment. To prevent any further encroachment of the river along the east bank, in case the current in future set in the same direction, two groynes or bunds were thrown out, the upper one, ½ mile in length, covering the lower and shorter bund, the latter forming a second breakwater in the event of the first giving way. The heart of the bunds was composed of sand and earth, topped and faced with stone; the land end was trenched and carried back into the high ground, to prevent the water getting in behind the groyne; while the other end was sloped well into the river, and composed wholly of stone. The abutments are similarly protected with stone, as well as each well pier. The Jumna was the first bridge on which the experiment of stone protection was tried. The result was most satisfactory; for it stood the test of another heavy flood season in 1872, again in 1873, and also in 1874. During floods, the bed of the river is in a semi-fluid state for a considerable depth, and scour is most rapid, but wherever stone is put in the scour is at once checked. The experience of four seasons has shown, from probings, that the stone does not move horizontally with the force of the current, but settles vertically, compressing the substratum, and that the scour takes place between the stone placed round the piers. As the vertical settlement progresses more stone is thrown in, but the quantity required has become less in each succeeding season.

Figs. 3 and 4 represent in elevation and in plan the west abutment, wing walls, and two spans of the Beas bridge, which were protected with stone in a similar manner. The set of one of the currents of this river was against this abutment, scouring deeply between the piers of the first two spans; as a further protection to this part of the work, a stone flooring was put in at low water in the dry season, as shown in Fig. 5.

Figs. 6 and 7 are examples of two piers at the Sutlej, showing the stone as put in during the dry season, and the position it took during the rainy season, the depths being obtained by probings taken after the floods. Figs. 8 and 9 are sections of one channel of the river, showing by soundings the scour before any stone was thrown in, and the result after the stone had been placed, from which it will be observed that the scour, which before took place immediately round the piers, now occurs between the piers.

The same system of protection has been carried out at the piers, abutments, and river banks of all the Company's bridges over rivers subject to floods, with precisely similar results. The probings since the floods of 1874 show an equally satisfactory state of things at the Jumna, the Beas, and the Sutlej bridges. When the piers are in channels, the stone is thrown from the top of the bridge; when the piers are dry at the time of low water, the sand and silt of the river bed are excavated to as great a depth as practicable, generally 5 feet or 6 feet below low water, and for 20 feet beyond the outer diameter of the well, and the stone is then placed by hand.

The Paper is accompanied by a series of drawings and models, from which Plates 12 and 13 have been compiled.

No. 1,274.—"Notes on the Consolidation of Earthworks." By JULES GAUDARD, Civil Engineer, Lausanne (Translated from the French by James Dredge, C.E.).

THE execution of earthworks for roads, and more especially for railways, is frequently hindered by landslips, sometimes of so serious a nature as to defy all the resources of the engineer.

In laying down the centre line of a road or of a railway, the regularity of the natural surface is not by any means the sole consideration. The attention of the engineer has to be carefully directed to the nature of the ground; he must avoid, as far as possible, deep cuttings in clayey soils, and, above all, in side-lying ground. Embankments, again, should not only be constructed of carefully-selected material, but they should be formed upon a natural surface solid enough to carry their weight without settlement.

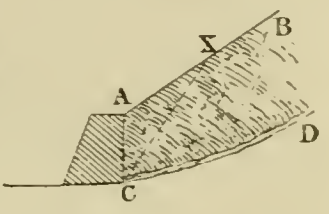
It is easy to lay down rules for dealing with simple and well-defined cases, but Nature for the most part presents complicated conditions for the engineer to control. Matter is not purely inert; it possesses, so to speak, a certain chemical or physical life, which becomes gradually converted either into change of material, or into motion.

In the simple case of a cutting or a tunnel in rock, the sides of the cutting or the roof of the tunnel may be left unprotected, provided the rock is sufficiently solid. But there are materials which, appearing reliable at first, disintegrate under atmospheric influences; and natural steep sloping beds or stratifications, which induce slips, are not unfrequently encountered. In such cases it is necessary either to give special inclinations to the faces of the earthworks, or to protect them with masonry. Or, instead of a cohesive soil, suppose a material, dry, homogeneous and easily disintegrated. In this case the question of stability would also be very simple, for this ground has the property of falling only at certain angles, depending upon its nature, according to which it remains more or less stable. If then the requisite space be available to give the proper slope, no difficulty presents itself; or when the base is limited, the weight of the earthwork can be sustained in a vertical plane by a retaining wall.

The theory of the thrust of earth against, and of the stability

of, retaining walls is well known. The theory does not aspire to exactness, but it suffices in practice, provided it is not applied in complex cases. Let the wall retain the weight A B, Fig. 1. Theory shows that the mass tends to slide along the line C X (straight, or rather curved), an intermediate angle between the vertical and the natural slope of the material. Supposing the earth to be in a disintegrated condition, A B lies between the natural inclination and the horizontal, and the prism of maximum thrust A C X is but limited, even when the side A B is indefinitely extended. In these conditions the wall can easily retain the earth behind it.

Fig. 1.



It would equally serve as a retaining wall for water, in which the limiting surface A B is of course horizontal. Mud, too, differs little from water, excepting that its density is greater.

But imagine that there exists in C D a water-bearing seam. This permeable bed, saturated with and discharging water, would evidently form a sliding surface, especially as it would almost certainly rest on a more or less impermeable clay stratum, the top of which, softened by the water, becomes slippery or greasy. Here the hypothesis of theory is destroyed, and it may be impossible to construct a stable retaining wall, on account of the great pressure behind, which tends to force it forward or overturn it. The earth towards the surface may also be cohesive, to such an extent that the surface A B has a greater angle than is due to its natural slope; the effect of this would be to increase the divergence between the limiting and the sliding lines A B and C D, and therefore the amount of the moving mass. Natural stratifications, or earthwork if laid in successive layers behind a retaining wall, also possess a certain sliding tendency, which destroys the hypothesis of the homogeneous theory. It is far preferable to form the earthwork in well-punned layers, in such a manner as to form stratifications, as it were, the sliding angle of which is in the opposite direction to the thrust against the wall.[1]

Retaining walls are often unable to resist the thrust of earth resting on natural sliding slopes. To check this action the footings of the wall should be taken down into the solid ground. Thus stratifications of soft ground can be preserved in their natural state, because the slope is reduced as the lower parts are reached. Even a comparatively light cutting in such a soil must be accom-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 143.

panied with danger. In all these cases, if the conditions are known beforehand, precautions can be taken so as to carry out the work without failure, and to retain the ground after it has been completed. To secure this, plenty of timbering is necessary while the work is in progress, and subsequently the earth must be retained by strutted walls, provided with sufficient outlets for the drainage. Such structures are not ordinary retaining walls, because they do not resist the pressure against them by the inertia of their mass; and they may be strutted either at the base or toward the summit, or, if necessary, both above and below.

The walls of the Blisworth cutting (London and Birmingham railway) are strengthened by counterforts strutted underneath the road bed (Fig. 2). Overhead strutting is applied in the case of

Fig. 2.

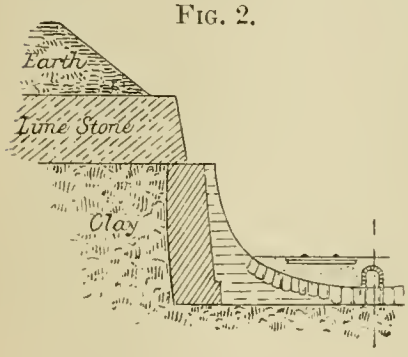
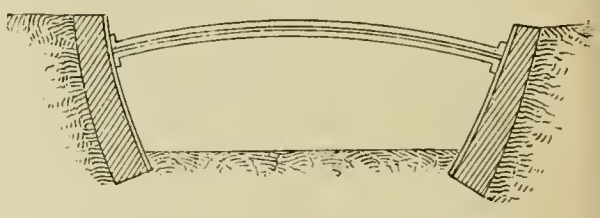


Fig. 3.



high walls, which threaten to turn over rather than to slide out at the base. Many cuttings in England are thus strengthened by cast-iron struts; as, for example, on the inclined plane at Euston (Fig. 3).[1] In the same Paper Mr. Hosking has noticed an arrangement of masonry struts, with counterforts spaced 21 feet apart; the wall itself being counter-arched between the counterforts, to check it from yielding under the pressure at the back (Fig. 4). Struts analogous to these are found at the Moseley tunnel (Birmingham and Gloucester railway). Finally, masonry struts, placed 15 feet apart, and of the form shown in Fig. 5, serve to strengthen the retaining walls of the Chorley cutting (Bolton and Preston railway). These are formed with upper inverted arches to give them additional stiffness. When the cuttings are in side-lying ground, the struts should be inclined (Fig. 6).

From works of this nature to tunnels there is only a step, as the latter may be adopted with advantage instead of very deep

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 358.

cuttings. The small tunnel of Bochat, near Lausanne, was subjected to the action of a landslip so severe that it involved an

Fig. 4.

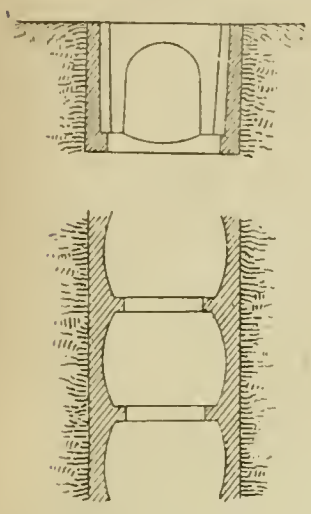


Fig. 5.

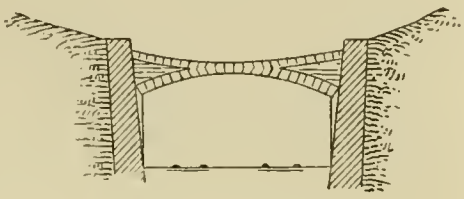
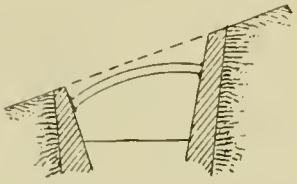


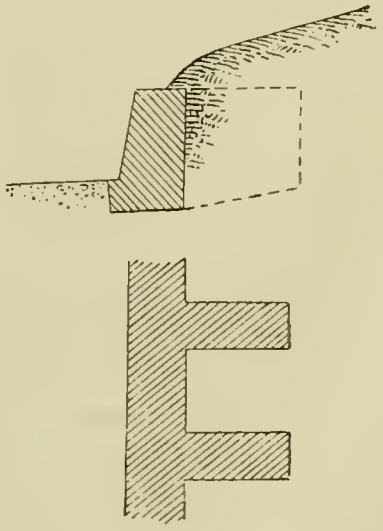
Fig. 6.



alteration in the profile of the line, a sufficient evidence of the difficulties that would have been met with had a deep cutting been attempted.

For overhead strutting, the use of iron appears to possess considerable advantages as compared with masonry, when the ground to be retained exerts variable thrusts, according to periods of rain or dryness; in this case it is to be feared that the arches, sometimes exerting a thrust against the walls, and sometimes being thrust by them, incur a danger of eventual failure. The iron arched struts should be made very flat; theoretically, they should only be sufficiently curved to counteract the deflection due to their own weight.

Fig. 7.



Many other examples might be given; but enough has been said to show, that the mode of strutting at intervals constitutes an efficient means of enabling the retaining wall of a cutting to resist considerable thrust. This mode cannot, however, be applied when there is only one side to retain, or when the heights of the two walls are very unequal. Then other methods have to be resorted to. For example, thick, dry stone walls may be employed, strengthened by long internal counterforts, as in Fig. 7. This

class of masonry acts as an efficient means of draining the slope behind, and it gradually becomes hardened into a compact mass, forming, together with the counterforts that strengthen it, a body of firm earth and stone able to retain the mobile material above. Examples of this form of construction may be seen on the Strasbourg railway. On the Lyons line, walls have been employed with dry stone backing, provided with openings through the front of the wall, which is laid in mortar, to discharge the water.

Inclined walls, as in Fig. 8, may often be more economically employed than those with a slight batter, because the whole of their weight falls on the ground which has a tendency to slip. An example of this may be found on the Versailles railway (left side). The slope of the cutting of Brigant (Blesmes-Gray) is supported by inclined arches (Fig. 9) laid

Fig. 8.

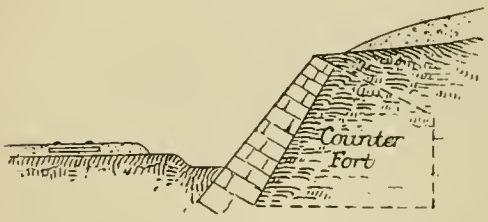
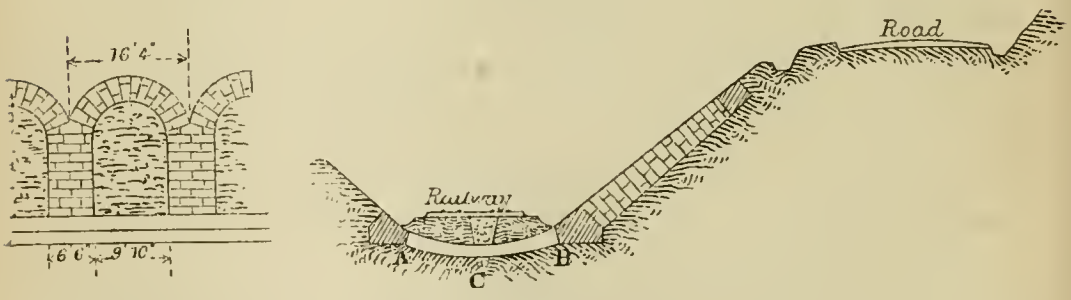


Fig. 9.

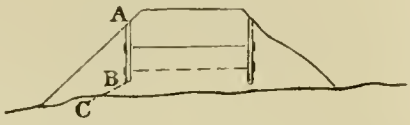


in the slope, the spaces between being filled in with dry stone. The bases of the piers rest upon a continuous footing, along the side of the roadway, connected with a similar one on the other side by means of inverts A B, at intervals across the track. These inverts are 39 inches wide, 20 inches thick, and about 16 feet 4 inches apart from centre to centre. The slope is drained by pipes leading into a central culvert, C, below the invert.

The cutting of Loxeville (Paris-Strasbourg railway) was first consolidated by a double row of pointed arches, having 6 feet 6 inch openings, and 18 feet high for each row, the piers of the upper tier resting on the keystones of the lower arches. The ground consists of a thick stratum of very permeable limestone, upon clays which become disintegrated by exposure to the air. As slips occurred upon this work, a careful system of drainage was established by means of ditches and benched collectors.

The principle of strutted sides can also be applied to unstable embankments, which it is necessary to hold in place, as it were, by a cofferdam. An embankment near the Sèvres station, on the Western railway of France, was held together in this manner. Oak sheet piling was sunk on each side of the bank, the two inclosing sides being coupled together by tie-rods, so as to prevent any spreading of the earth. Fig. 10 shows this arrangement. The side slopes were not disturbed; but they only play a small part in the whole, because the lack of adhesion between the earth and the oak piling would encourage the falling away of the prism A B C.

Fig. 10.



Physical Causes of Landslips.

So far only the question of retaining earth mechanically has been considered. Walls are often too costly, and are, moreover, in many cases, unreliable. The physical considerations, which play an important part in the problem, and which lead the engineer towards other remedies, will now be dealt with. The most dangerous landslips are not those which take place suddenly and without previous indications, but rather those which are slow and progressive. Frequently they do not occur until two or three years after the execution of the works which induced them. This fact would indicate that the vibration of passing trains helps towards the catastrophe.[1]

It is worth noticing that in canals, which are not subjected to the same vibration as railway works, the ground may become consolidated at the end of a few months. The approach of dislocation is indicated at first by simple fissures, then by small quantities of falling earth, which gradually increase in mass until the entire fall takes place. Such accidents are especially frequent in loamy soils combined with permeable or water-bearing seams. The clay, softened by the water, gradually forms mud. It is true that plastic clay, confined and well consolidated so that it cannot move, forms an impermeable mass able to resist great hydraulic pressure; and it is this property that renders the material so valuable in the construction of cofferdams. But natural beds of clay are seldom homogeneous; they are frequently schistous, and combined with other and soluble or oozy materials, traversed

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 170.

by fissures, worm-holes, or the roots of vegetables; and, finally, clay is highly susceptible to deleterious atmospheric influences.

It will be clearly seen, therefore, that loamy or marly soils, more or less impure and subject to the action of water, become finally disorganised, and fall, at first in small fragments which detach themselves from the main body, and afterwards with more rapid movements, which affect the whole mass as soon as the conditions of equilibrium are changed. Mr. Charles Hutton Gregory mentions[1] experiences gained on the London and Croydon railway, and especially in the New Cross cutting. Two classes of clay were met with—compact London blue clay, and a yellow clay so impure, so full of fissures, and so impregnated with saline materials, that it formed really a highly permeable earth, which could be quickly changed into slimy mud. In the North of Spain a heavy cutting, also lying through a yellow clayey soil, had to be abandoned, and the centre line of the railway shifted.

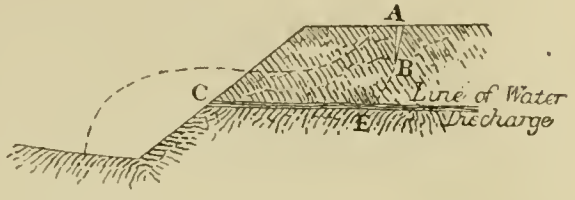
In certain cases chemical agency is active, and an internal molecular action is set up, which disorganises the mass, impregnates it with water and gas, and changes the actual volume of the material. Thus Mr. Gregory mentions the presence of iron pyrites in yellow clay, which being decomposed by the action of the weather, generated sulphuric acid, that in its turn decomposed the carbonate of lime, and formed crystals of selenite. Mr. Clutterbuck remarks that the blue London clay contains protoxide of iron, and that the superficial beds exposed to the action of the air owe their yellow colour to the transformation of the protoxide to a peroxide.

The action of the atmospheric agencies may be thus explained. Clay, which in the lower beds is comparatively soft but compact, and with slight variations in density, varies greatly, on the contrary, when exposed, according to the state of the weather. In times of heat and dryness it contracts and cracks, whilst after a rain which penetrates the fissures, the clay distends. Renewed dryness reopens the cracks and increases them, and again the water penetrates deeper than before, while pieces become gradually detached from the surface of the slope. The first slip increases the fissures, uncovers portions previously preserved and sustained, and gives an impulse to new derangements, which are gradually extended. The existence of water-bearing beds within the clay augments the danger, not only on account of the water weeping upon the face of the cutting, or, changed in its regular action by a partial falling of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 135.

the slope, and acting in the fissures in the same manner as rain—but also because they constitute natural slippery fissures, which complete and hasten the detachment of large masses. Thus, when the fissure A B, Fig. 11, descends near enough to the water-bearing seam C E, the fall of the mass A B E C is imminent, although no disorganisation other than the fissure A B has occurred. When the fall takes place, a new face is exposed, less stable than the orginal slope, the loam soon changes into a state of semi-fluidity and of unstable equilibrium, unable to sustain itself at any angle.

Fig. 11.



Frost and thaw contribute also to the destruction of the sides of a cutting. The former hardens and compresses the soil, then the thaw, reducing the water in volume, destroys the cohesion of the earthy particles, and predisposes them to melt in the water; an effect which declares itself immediately by the swelling of the clay. This evil is, moreover, greatly increased if the bed, hardened by the frost, contains water-bearing seams; for, when the thaw takes place, an accident is imminent from the sudden discharge of the liberated water. Heavy rain-storms also exert a mechanical action by their volume and velocity; they wear and furrow the surface slopes, where the rapidity of their flow may become considerable.

Clay soils are not the only ones which offer obstacles to the execution of heavy earthworks. Certain water-bearing sands are quite fluent, on account of their permeability; peaty grounds are compressible, and sink under superimposed loads; tufa and marl, firm when protected from the action of the air, quickly disintegrate under atmospheric influences. In the Clamart (Paris-Rennes railway) cutting, it has been sufficient to protect the slopes with masonry revetments, or with vegetable earth well rammed.

In mountainous districts, heaps of fallen materials are met with, fed constantly by the slopes and the rough action of the weather. It is necessary to arrest these moving soils, either by fascines, by plantations, by retaining walls, or by other means. It is especially in schistous formations that the limiting slopes are unstable, being composed of laminated masses. For the most part, these formations, situated in a locality favourable to vegetation, are covered with plants which consolidate them in conjunction with surface accumulations. Under these circumstances they can sustain certain weights of embankment, even if they cannot be opened to

form deep cuttings. Feldspathic rocks often contain veins or pockets of clay; and, lastly, clayey schists are equally unsafe, especially where they present sliding faces considerably inclined towards the cutting.

Watery seams are dangerous, although sometimes they are so thin as not to be readily apparent. They discover themselves, however, on the side of a cutting by the water which passes from them. In cuttings already completed, it is at sunrise that these slight filtrations are most apparent. If necessary, the side may be sprinkled with sand or ashes, which will indicate the position of the humid deposit. If these are visible in bright sunshine and in dry weather, they reveal, as a matter of certainty, the existence of internal water. Roots of trees sometimes produce humid filtrations, and it may occasionally happen that weeping takes place between two beds of clay, and not only at the bottom of sandy deposits.

The chief means of dealing with these slippery formations consist—1, in insuring the free discharge of the water by means of channels, drains, or filters, in such a manner that the ground shall be gradually dried and consolidated; 2, to take off the rain or surface water as rapidly as possible, by means of impermeable coverings, benches, or ditches; 3, to preserve the loamy soils from the action of sun, rain, and frost, and sometimes to protect the foot of the slopes with walls, or simple counterforts of well-rammed earth. Success has in general attended the adoption of these measures, when they have been applied with judgment. Nevertheless, it will always be prudent in executing work in bad ground to avoid deep cuttings or high embankments, to increase the side slopes, and to abstain from carrying out these difficult works in bad weather. The drainage especially requires favourable weather, and it should be conducted simultaneously with the works, to lead off the water from the excavation carried to spoil. The best season is included between the months of March and September.

Concerning the proper slopes to be employed in cuttings in bad ground, it is well to increase them to 2 or 3 of base to 1 of height, instead of employing $1\frac{1}{2}$ to 1, or 1 to 1, which are applicable in good material. This reduction only applies, in some cases, to the slope or strata inclining towards the railway; the opposite slope can be formed with a greater angle. The theoretical form of the sides should be slightly concave, a form observed after landslips.

The conditions involved in the formation of efficient drainage

and protection of works and of cuttings will now be considered; passing on next to the question of repairs necessary after the occurrence of a landslip, and then a few words will be added on the consolidation of embankments. The principal sources whence this information has been drawn are:—Nouveau Portefeuille de l'Ingénieur des Chemins de Fer, par Perdonnet et Polonceau, p. 128: and from the Documents, Rapport de M. Daigremont, p. 73, and a very complete Memoir of M. Bruère, p. 103, also p. 153. Traité de l'entretien et de l'exploitation des Chemins de Fer, par Ch. Goschler, 1st volume, Traité pratique de l'entretien des tranchées et remblais. Minutes of Proceedings of the Institution of Civil Engineers, 1844 and 1845.

Cuttings.

The side slopes of a cutting may be drained by the construction of channels (Sazilly system) if the water-bearing seams are clearly defined; by pipe drainage if the distribution of water is more vague and general; and, lastly, by filtration in the case of water-bearing sand.

1. In water-bearing strata.—In some instances a deep, narrow trench has been excavated in the bank, at a sufficient distance from the face of the slope, the sides of the trench being timbered and filled with dry stone (Fig. 12). The planes of moisture in the

Fig. 12.

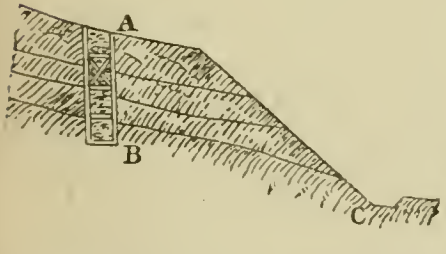
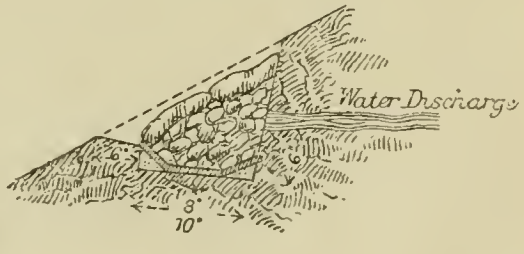


Fig. 13.



prism A B C dry up, and the earth gradually and surely becomes consolidated. This method is good, but costly; it may be employed to arrest movement already commenced. It is generally sufficient to fill only a part of the trench with stones, which may then be covered with moss, straw, or turf, and the filling-in may be finished with rammed earth.

Sazilly[1] devised a more economical system of small longitudinal

[1] *Vide* "Annales des Ponts et Chaussées." 3ᵉ série, 1851, 1ᵉʳ sem. p. 1.

drains, established near the face of the slope, and formed in the vicinity of the seam. At the bottom of a cutting in the face of the slope (Fig. 13), is placed a channel, formed transversely of three tiles set in hydraulic mortar. The tiles employed for this purpose are 3·15 inches wide, and ·787 inch thick; or the channel can be more simply formed with a single row of ordinary half-round tiles. Round or broken flints, 2 inches or 2½ inches in diameter, or sometimes furnace slag, are thrown over the channel. The larger pieces are placed below, and the smaller nearest to the water-bearing seam. This stone filling, heaped against the vertical side of the cutting in the face of the slope, is always high enough to cover any irregularity in the line of the water discharge. The surface may be covered with turf, or with a layer of clay or matting, with tiles, or with flat stones, to keep out the mud which would gradually choke the drain. Two lines of water discharge, at least 18 inches apart, can be served by the same channel. This system of drainage is laid in the face of the slope, with gradients of at least 1 in 100, and at their successive lowest points they discharge into the side drains of the railway. The cost ought not to exceed one shilling per lineal yard.

It is necessary to protect the whole of a slope of loamy soil with a covering against the action of the rain, sun, and frost. The revetment may be executed in earth, in successive layers from 6 inches to 8 inches thick, laid with a slope opposed to the face of the bank. Vegetable earth is suitable, or clayey sand, or a mixture of clayey marl and vegetable earth. A certain proportion of friable clay has even been added without inconvenience, as, for instance, on the Hundsoff and Strohübel cuttings on the Wissembourg line. Ramming renders the bed almost impermeable; nevertheless M. Bruère recommends the formation of a small drain at the foot of the slope, to carry off such of the surface water as may have penetrated through the revetment. Finally, the surface is sown or planted with couch grass, clover, lucerne or French grass; occasionally with shrubs, acacia, willow, birch, maple, &c., the deep roots of which spread, compressing and consolidating the ground. Care must be taken at all times to prevent the roots from choking the drainage channels.

Sometimes trenches or furrows are formed in the face of the slope to give the protective covering a better hold (Fig. 14); but this is not necessary when the inclination of the slope is small. The base is frequently finished by a stone revetment. Revetments of rammed earth are better and less costly than stonework, which permits the infiltration of water. Ordinary turfing would be

insufficient, whilst turfs laid as in Fig. 15 would be costly, and still permit water to enter between the interstices.

Fig. 14.

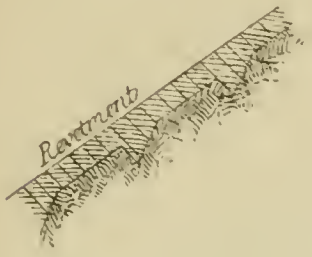
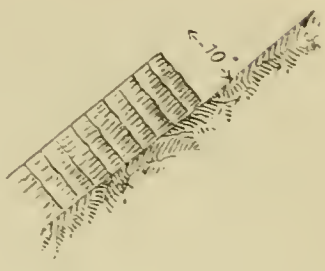


Fig. 15.



In deep cuttings, and especially in those which are commanded by a higher natural slope, it is of great importance to check the action of the surface water in its descent, in order to prevent the scouring of the sides. With this object a ditch is often formed at the foot of the natural slope (Fig. 16), as, for example, in the Morcerf

Fig. 16.

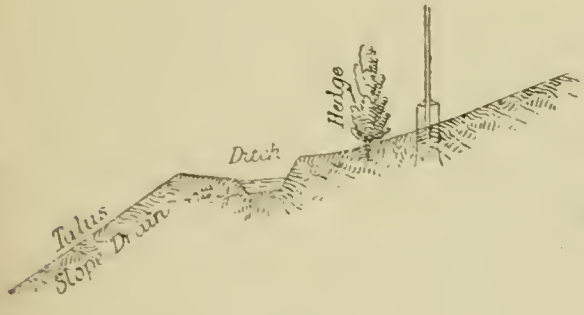
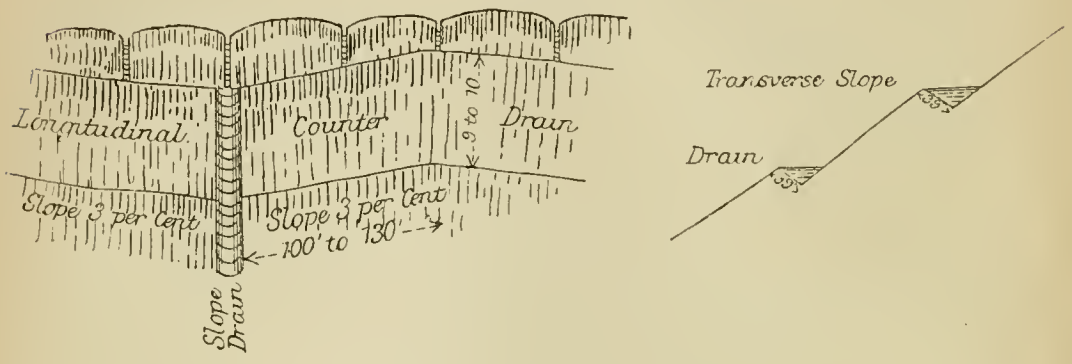


Fig. 17.

and Guérard cuttings on the line from Paris to Coulommiers. This ditch must be of clay, puddled to make it impermeable; it collects and carries off the water coming from the higher levels. This method is open to the objection that it disturbs the integrity of the surface, and thus affords facilities for the percolation of water, which may affect the stability of the work. An open channel in stone or brick is better (Fig. 17); but there is still a more preferable mode. This consists in dividing the face of the slope into a number of stages, in such a manner that the dangerous action of surface water is greatly reduced. Each of these benches prevents the water from acquiring velocity as it descends the surface, and retains it at each bench on account of a reverse inclination of 15 per cent. being given (Fig. 18). Lastly, it conducts the water by the longitudinal face towards drains laid at intervals on the surface of the slope. These slope drains

are sometimes, for the sake of economy, turfed as in Fig. 15, or planked, or formed with tiles. But when they are placed so far apart as to receive large quantities of water, it is advisable to construct them in masonry set in hydraulic mortar, with joints

Fig. 18.



faced in cement. Thus formed they should cost about 3*s.* 5*d.* the lineal yard if 39 inches wide. The side ditches themselves ought to be protected with stonework, especially at the bottom, and towards the main slopes; or, at least, they should be flat turfed.

As to the banquettes, which receive only a small quantity of water, and the slopes of which are moderate, they are simply covered with properly-rammed earth, or are flat turfed, the joints being made good with vegetable mould. The revetment of a slope, including banquettes, drains, ramming, &c., ought to cost from about $6\frac{3}{4}d.$ to $7\frac{3}{4}d.$ per yard, or perhaps $9 \cdot 3d.$ per yard, including the extra excavation, which is afterwards made good by the covering of rammed earth.[1]

Fig. 19.

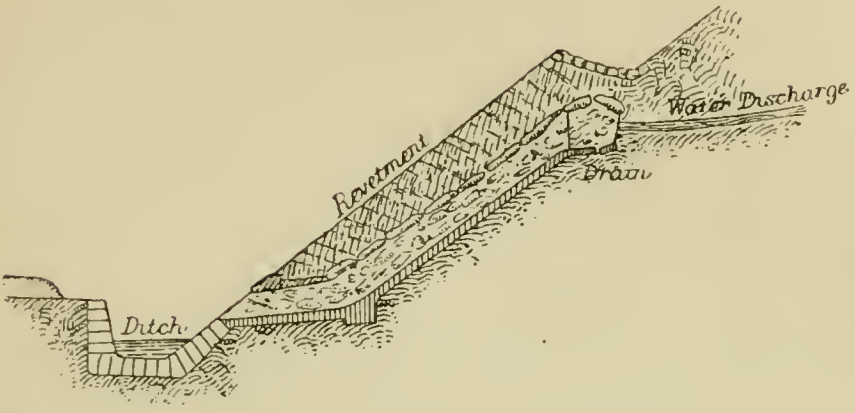
The width of the benches may be varied a little, in order that the general profile of the cutting may approximate to the curved form which a natural slope would assume (Fig. 19).

The channels, up the side of the cutting, which take off the water from the trench drains, may be either open in masonry, or, better (Fig. 20), formed of small stones, covered by the revetment, and resting on the natural ground. It will be convenient to make a banquette immediately over the head of

[1] *Vide* "Nouveau Portefeuille de l'Ingénieur," par Perdonnet et Polonceau. Documents, pp. 150–151.

the sloping drain, to give facility for examining and maintaining the latter.

Fig. 20.



Pipe Drainage.

When the water-bearing seams are numerous, irregular, or indistinct, pipe drains may be employed, wherever any discharge of water shows itself. These form narrower channels than the Sazilly drains already described, and this feature renders them inefficient to draw off the water from well-defined seams. But when these latter are more scattered, the earth has sufficient permeability to allow the whole of the moisture to percolate to the drains, provided only that these are placed close enough together. The drains are laid at the bottom of narrow trenches. It is advisable to pack the joints with moss or reeds to prevent them from being stopped up too easily; and sometimes they are protected by sand and small stones, covered with moss, straw, or turf, and the trench is finally filled with rammed earth.

In England, especially on the Croydon and Birmingham rail-

Fig. 21.

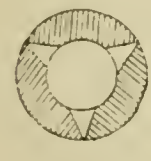
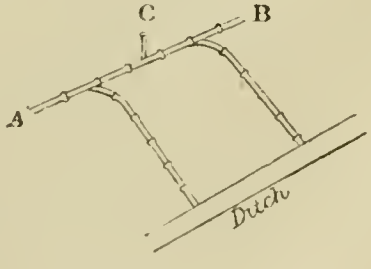


Fig. 22.

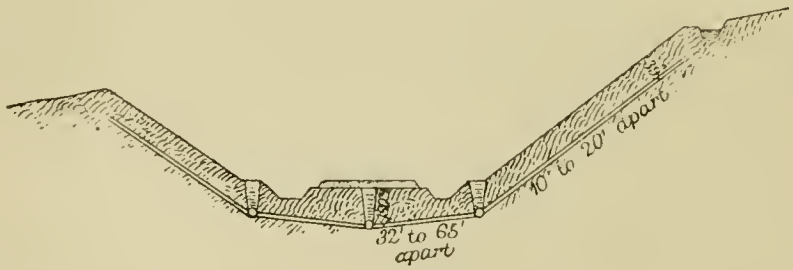


ways, the efficiency of these drains has been increased by making numerous small openings in them enlarged towards the inside

(Fig. 21).[1] Owing to the form of the holes, any mud which may enter from the outside of the drain frees itself immediately and passes off with the water. The joints are formed with sockets. A line of drain pipes (Fig. 22) is placed along the crest of the slope, and from this others descend transversely into the side ditch. At regular intervals a vertical pipe, C, rises from the main line, for the purpose of ventilation. The circulation of air thus obtained causes the deposit left in the pipe, in dry weather, to crack, and thus it is easily removed the first time water passes through the pipe; but, on the other hand, this arrangement encourages a choking vegetable growth within the drain. The pipes are laid 5 or 6 feet below the surface, towards the foot of the slope, and 3 feet beneath at the top. They are spaced about 15 feet apart.

On the railway from Blesmes to Gray, M. Ledru laid 1·18-inch drain pipes in the slope, 39 inches below the surface (Fig. 23), and

Fig. 23.



at intervals of from 10 to 20 feet, according to the moisture; these discharged into longitudinal collectors, placed near the side ditches. A third central collector drained the roadway, and was placed in connection with the two lateral drains by pipes laid from 32 to 65 feet apart. They are formed of pipes 3·34 inches diameter, and are covered with broken stones.

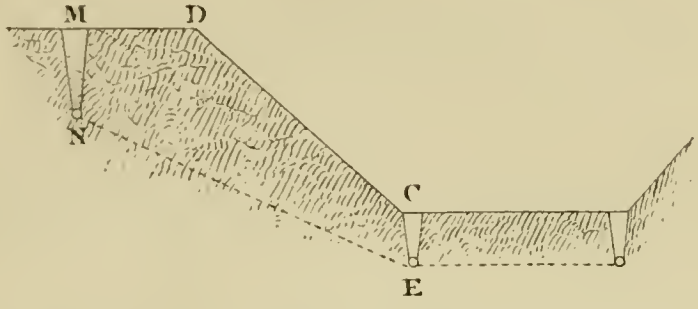
When the upper part of the bank only requires draining, it is sufficient to lay down a longitudinal line of pipes or tubes discharging into the open air.

M. Daigremont employed, on the Eastern railway of France, a system copied from Germany, or perhaps rather from England, because it is almost identical with that described by Captain Moorsom.[2] Drains at least 2·36 inches diameter, surrounded by a filtering material, and with a minimum inclination of 1 in 200, are laid in a deep, narrow trench M N, to the rear of the top of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 78.
[2] *Ibid.*, vol. iii., p. 158.

the slope D C, Fig. 24. On that side of the trench farthest from the face of the slope are placed small vertical pipes about 6 feet 6 inches

Fig. 24.



apart, and 1·45 inch in diameter. These pipes are stopped short of the surface of the ground, and are closed at the top with plugs of reeds, while they communicate below with the longitudinal drain. The trench is then filled with earth and well rammed. Other collectors beneath the side ditches drain the formation to a depth of about 4 feet. The mass M N E C D being thoroughly drained by this means, acts as a counterfort to resist the thrust of the moist ground behind M N, and the slope D C may even be made with an angle of 45°. It is urged against this system that the trench M N would encourage the disintegration of the earth, and that in bad ground the deep, narrow trenches would be costly in execution, especially where timber was necessary. M. Daigremont describes[1] applications of this method of longitudinal trenches in the cuttings of Petit-Croix, Dannemarie, &c., and he adds data concerning their cost. In the Dockemberg cutting, transverse galleries have been driven to drain the slopes.

Here may be mentioned the Ashley cutting on the Great Western railway,[2] which was drained by a system of inclined transverse galleries and of sumps, connected by a longitudinal gallery in such a manner as to tap all the water-bearing seams. On the Great Eastern railway (Brentwood Hill cutting), the slopes were drained by sumps filled with broken stones, and by discharge drains.[3] On the Lyons railway, M. Jullien also sank shafts to the water-bearing deposit, and effected the drainage by discharge pipes.

A cutting in the North of Spain, on the line crossing the Pyrenees, was attended by landslips, although the stratifications

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[1] "Nouveau Portefeuille de l'Ingénieur," par Perdonnet et Polonceau. Documents, p. 80.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 129.

[3] *Ibid.*, p. 160.

(marl, clay, schist, sand) were normal to the face of the upper slope. In such a case the water is retained in pockets, and can only be removed by a syphon. Collecting wells were sunk, and surrounding trenches were made, as well as a system of galleries.

On the Western railway of Switzerland, M. Lelanne laid rows of drain pipes in the slope, Fig. 25, in such a way as to dry a

Fig. 25.

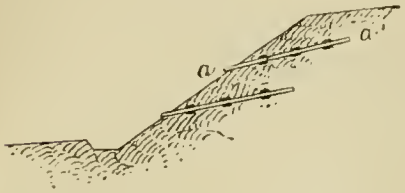


Fig. 26.

considerable thickness of earth. A number of pipes are joined together with sleeves, as shown in Fig. 26, m, m'. These joint-sleeves are kept at their proper distance apart by means of an iron wire which connects them together. The length of pipes is then introduced into the hole formed in the face of the cutting by a boring tool. The method is not applicable in cases where the earth has been much disturbed. Care must be taken that the orifices of the pipes, which project slightly from the face of the slope, do not become choked with mud, or frozen, and the slope ought to be well turfed under the points of discharge. Perforated pipes would be preferable to the ordinary plain ones, which are so easily obstructed.

In the retaining wall at Euston (London and North-Western railway), holes were made to admit 3-inch drain pipes of cast iron, to a distance of 4 feet. The wall was thus relieved of a thrust which threatened its destruction. When in course of erection, the rear face of such a wall may be provided with a kind of grating, discharging through perforated pipes.[1]

M. Goschler gives, in his "Traité des Chemins de Fer" (vol. i., p. 56), examples of draining the road bed of a railway, by means of masonry channels, or by drains.

In conclusion, the mode of draining by means of clay pipes appears to be that chiefly used, and most favourably thought of. Thanks to the play permitted by the joints, the pipes can accommodate themselves to slight settlements, which would of necessity dislocate the Sazilly drain. Besides they can be laid at a considerable depth with but little excavation, and they answer their

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 78.

purpose well, when the body of water to be carried off is not so excessive as to require the construction of more important works. They are generally of small diameter, and are laid in parallel rows, following the face of the slope, discharging into longitudinal collectors of larger size, placed either at the sides or in the centre of the road bed. For these longitudinal drains the fall ought not to be less than 1 in 200.

As examples showing the importance of the cost of drainage, the following are borrowed from M. Couche:—

At Virecourt (Blainville-Epinal line) for 2,990 square yards of slope, there are 630 feet of secondary drains, and more than 920 feet of collectors. At Sourbourg (Strasbourg-Wissembourg) 1,290 square yards of slope are drained by 920 feet of secondary drains, and 1,800 feet of collectors. The average cost per lineal foot of the drain, laid complete, may be taken at 7*d*. Lastly, 2-inch drain-pipes, sunk to a depth of 3 feet below the rails in the Maranvillier cutting, cost about 9*d*. per lineal foot.

Filters.

In water-bearing sands, which discharge from their whole mass, drainage can only be partially successful, and it is necessary to have recourse to filtering appliances, covering the whole of the slope which is to be consolidated. On the Northern railway of France a stone facing, from $4\frac{3}{4}$ inches to 6 inches thick, covered with stone packing, or turf, $11\frac{3}{4}$ inches thick, is adopted. A 9-inch or 10-inch revetment is sufficient to keep out the frost which would stop the water discharge. When there is an abundant flow of water, the filters should be of considerable thickness, and the best mode is then to adopt 'gravel fascines' (Fig. 27). They are

Fig. 27.

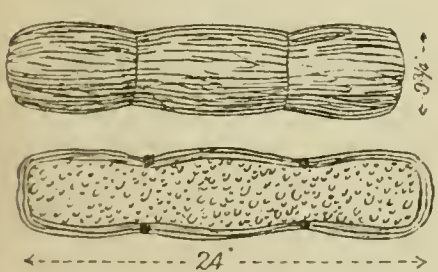
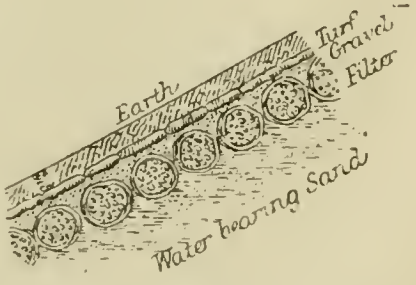


Fig. 28.



formed of envelopes of brushwood, fastened by fascine bands, osiers, or iron wire, and well filled with gravel or broken stone. These fascines are laid in horizontal furrows formed in the face

of the slope (Fig. 28). It is a somewhat delicate work, and must be executed rapidly, commencing from the top of the bank, so as to avoid the inconvenience of the water passing off. A layer of gravel about 4 inches thick is put on to equalise the surface, then a protective cover of flat turfing, and finally 6 inches of vegetable earth. M. Bruère has, amongst other similar works, drained the Schautz cutting on the Wissembourg line.

Sometimes, in very fluent sands, the side ditches of the road bed fill in as fast as they are made. The most efficient remedy against this is to place first two fascines, as shown in Fig. 29, and to

Fig. 29.

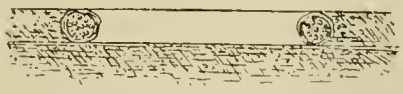
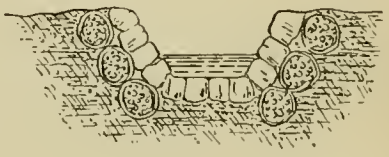


Fig. 30.



excavate the intermediate material. At the end of a few days the upper bed will be drained, and two other fascines may be laid at a lower level, and so on; finally, the ditch is lined with stone (Fig. 30).

Restoring Cuttings after Landslips.

When a landslip is not very considerable, it is sufficient to raise it completely and promptly, so as not to allow time for fresh slips. The new ground is then properly drained and strengthened by a counterfort.

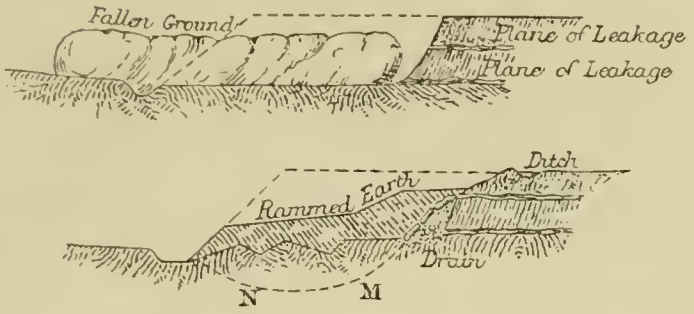
On the line from London to Birmingham, and on the Croydon railway, some local slips were restored with counterforts in dry stone and gravel.[1] The spaces between the counterforts may be made good with rammed earth. On the South-Western railway hard chalk has been successfully employed in the construction of counterforts, instead of gravel.

In the Briel cutting on the Mulhouse railway, a Sazilly drain was made to collect the water. The cavity left by the slip was refaced with a layer of rammed earth, and the lower points of the Sazilly drain were joined with the side ditch of the way by transverse channels. In such cases it may happen that the glacis, M N, of the slip may be below the level of the side ditch; it is

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 144.

then advisable to make it up again with earth carefully rammed (Fig. 31).

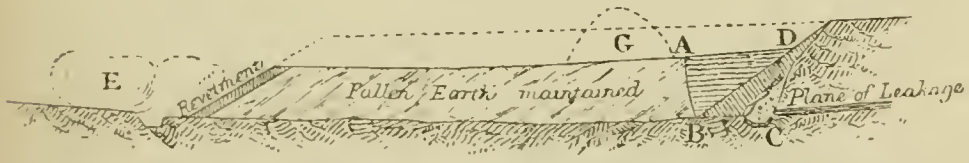
Fig. 31.



Certain slips on the Paris-Coulommiers line required the application on the new ground of two or three tiers of drains, connected with the ditch by transverse drains.[1]

With landslips on a larger scale, the great labour of bodily removing the whole of the fallen material has been sometimes undertaken, the saturated loam being difficult to drain properly, as, for instance, the New Cross cutting on the Croydon railway.[2] But such a course is long and costly, and in many cases the principal part of the fallen earth may be left in place, if care be taken to consolidate it by the construction of drains which shall remain connected with the points of natural outflow. This was done successfully, for example, in the Hundsoff cutting on the Wissembourg railway. An excavation, A B C D (Fig. 32), was made of

Fig. 32.



sufficient extent to lay bare the undisturbed ground, and at the foot an open drain, C, was formed. If the material be very soft this excavation must be timbered, but it is sometimes firm enough to allow of the earth excavated being temporarily thrown up on the top of the slip, as at G. The drain is covered with turf, then a rammed-earth counterfort, B D, is formed, and finally the excavation is filled in again with the earth taken out (G). If the fall of the glacis or water-bearing line is insignificant, it will be sufficient to

[1] "Traité pratique de l'entretien et de l'exploitation des Chemins de Fer," par Ch. Goschler, vol. i., p. 44.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 135.

clear away the portions, E, which have fallen on the way. The masses at the rear will by this time have consolidated sufficiently to remain in place, in spite of the forward parts being removed, and a new face slope is formed, which is covered with 12 inches of rammed earth. The top surface of the slip ought to be evenly dressed, and all cracks and openings stopped up, to prevent the penetration of rain water. In landslips of considerable length and parallel to the way, it is advisable to form transverse cuttings at intervals, connecting the low points of the drain with the side ditch.

There is no cause for surprise that a bank, which has been little more than a mass of fluent mud, can be preserved without fear if it has been thoroughly dried. The action of water followed by a drying process produces an active compression and cohesion. The only danger to guard against is the return of the work to its original state.

M. Bruère gives, in Perdonnet's Nouveau Portefeuille (Documents, page 172), details of the drainage of a landslip at Briel. The sides of the slip were first trenched out in successive lengths of 12 or 15 feet, and a drain constructed at the bottom, which was covered by the earth taken out of the next length. When the rear of the slip was reached it was necessary to proceed cautiously, and in 10-feet lengths of well-timbered excavations, for the filter wall. The forward portion was also drained, and supported by an earth counterfort.

It is especially advisable, in cases where the angle of slip is considerable, to prevent the recurrence of such an accident by retaining the ground with a rammed earth-bank, separated from the slip by a filtering wall of broken stones (Fig. 33).

Fig. 33.

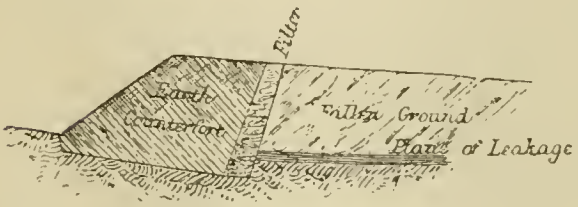
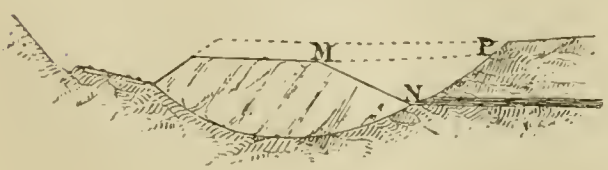


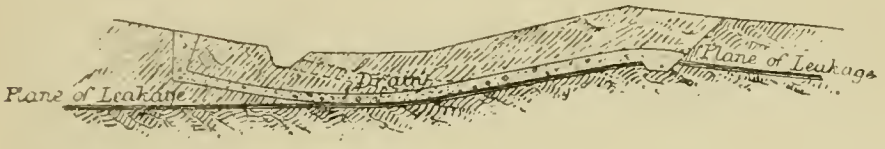
Fig. 34.



Sometimes the slip hollows out the subsoil, remains more or less charged with water, and tends to fall further upon the road bed. It is then preferable to excavate the upper portion, M N P, Fig. 34, and at the same time the face, N P, is exposed for drainage.

When a slip occurs in ground wherein occur water-bearing seams of considerable extent, it is necessary to effect the drainage by means of gravel filters of large area. Such a work has been executed on certain parts of the Soultz cutting (Eastern railway of France), where a bank of clay is permeated by water-bearing lines, which, extending for a considerable distance, produce dislocation of the surface. The filter (Fig. 35) which drains the bank, discharges at intervals into a channel formed along the centre of the road bed and to which sufficient fall is given; in the intervals, the filters

FIG. 35.



drain simply into the side ditch. In other portions of the same cutting longitudinal and parallel furrows, separated by banquettes, were formed in the uncovered clay. These furrows were protected by stone, and were intersected by discharge drains into the side ditches. The whole was then re-covered with good earth, brought down with the slip, the wet loam being carried to spoil.

It is absolutely necessary to deal with landslips with the utmost celerity, in order to prevent their spreading, a casualty which always renders them costly to repair, and sometimes restoration becomes impossible. The works require careful watching for a year or two. To clear away obstructions, to maintain the slopes, to prevent the accumulation of water, to break the ice which in winter stops up the drains, and to preserve and encourage the vegetation of the slopes, are all duties which must be carefully performed. An obstruction of a drain reveals itself by filtration, which appears on the surface of the earth revetment.

THE CONSOLIDATION OF EMBANKMENTS.

Under the most favourable circumstances, newly-excavated embankments of considerable height settle more or less, and this settlement may even continue during several years. Thus it is expedient to raise the profile of the work slightly, it being easy to repack the ballast. Wagon-tipped banks are not so consolidated as those formed with carts, and which are subjected to the trampling of horses. In forming a bank over culverts or other struc-

tures (travaux d'art), it is necessary to tip the earth equally on both sides, and to ram it as the work proceeds, in order to avoid throwing a mass on either side, which would produce a dangerous thrust against the masonry.

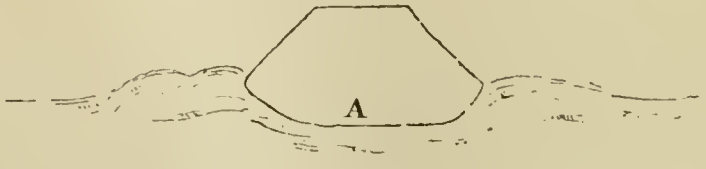
It sometimes happens that great difficulties are encountered in forming embankments, either on account of the nature of the ground on which they are formed, or because of the bad material of which they consist.

First Case. Yielding Foundations.

When the ground of the valley is compressible, or is composed of sliding clay beds, with inclined water seams, the weight of the embankment will set in motion this unstable base, which will sink unequally, or slip in the direction of the transverse slope. In the uncertain soil of Brittany upheavals from 6 feet 6 inches to 14 feet in height are noticed, which spread on each side until they measure from 120 feet to 200 feet in length. Certain soils, peaty from the surface downwards, sink as much under a small as under a large bank. Others, covered with a thin but firm layer, resist for some considerable time heavy but localised pressures; then, when the embankment becomes extended and completed, or when its weight has been sustained during a certain time, a great subsidence suddenly takes place, arising from the rupture of the surface crust, and which soon spreads over the whole extent. Such a rupture occurred, for example, on the Hanwell embankment of the Great Western railway.[1]

Often the best and simplest remedy is to add new material to the embankment as it sinks, until further settlement ceases. Banks of this class in Brittany have thus absorbed two or three times their original volume, and this mode may soon become too costly, if there is not sufficient excess from adjacent work, or an ample quantity within easy reach. In compact peaty ground the lower

Fig. 36.



portion A, Fig. 36, assumes the form given in the sketch, without sinking to any great depth, whilst in very soft material the bank

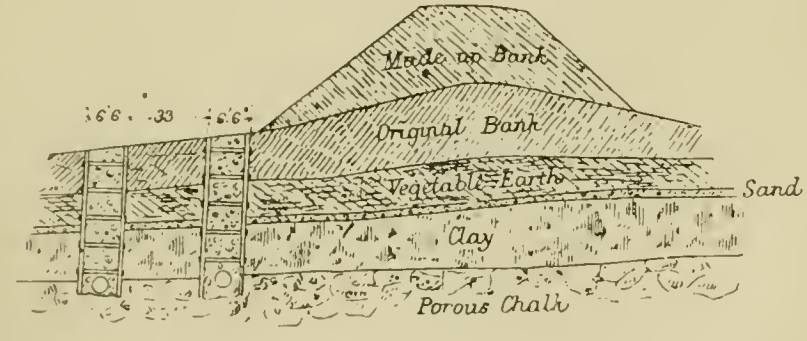
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 164.

may sink bodily to the solid bed, forcing away the yielding ground on each side. In steep valleys the earth will yield on the lower side and cause the bank to slip.

When the faulty bed of the subsoil is too thick to be passed through or to be removed, two courses are commonly employed to check derangement: to endeavour to improve the nature of the uncertain foundation, and to reduce the pressure exerted on it by the earthwork.

The condition of the subsoil may be sometimes improved by compressing or confining it; for example, by driving a large number of short piles, or by excavations in the form of truncated pyramids, filled afterwards with compact clay. This is a German method, an example of which from Hattenhofer, on the Münich-Augsburg line, is given in the "Annales Françaises des Ponts et Chaussées," 1845. But generally the true solution consists in draining the subsoil, which, once dried, acquires sufficient solidity. For instance, the embankment at Val Fleury (Versailles railway) sank, breaking up the foundation, and as it was not considered safe to raise it again to the necessary level, the difference was made good with trestle work. After the lapse of some years, however, it was resolved to restore the embankment, and two large parallel drains were formed on the lower side (Fig. 37). These

Fig. 37.



drains, from 39 feet to 50 feet in depth, were connected together, and led all the water away in such a manner that the foundation was dried, and was surrounded and maintained as by a protecting belt.

Between Otzaurte and Oazurza, in the North of Spain, moist valleys are met with, where the soil of clay and marl slips on schistose strata. Several embankments on the northern line yielded at the base, and it became necessary to surround the area on which they stood by a double network of drains; encircling

ditches with discharge culverts for the surface water; then for the internal drainage, galleries 5 feet high and 39 inches wide were driven along the schist, and cutting into it from 15 inches to 20 inches at least, in order to stop subsequent movement and to drain the sliding surface. These galleries followed the irregularities of the rock in such a manner as to involve slopes of from 1 in 33 to 1 in 17. They were then filled with a mass of broken stone, leaving a space at the top, clear of the fissures which admit the water. Driving such galleries is less likely to bring about land-slips in ground of this nature than open excavation; it should, moreover, be more economical at depths greater than 16 feet.[1]

In order to reduce the weight of an embankment on the foundation, it is necessary to construct it in light materials, and to enlarge the base. The embankment close to the Cubsac suspension bridge (Dordogne) was formed with voids in the interior of the mass. The base is increased by reducing the slopes, or, better, by lateral counterforts. Lastly, it is often advisable to construct the bank on a double tier of fascines, placed obliquely and crossing each other. These form an elastic bed, light, and able to drain the superimposed mass; and they prevent partial and unequal settlements by dividing the load more uniformly over the foundation. This was done, for example, on the Beaucaire canal. The Chatmoss (Liverpool and Manchester railway) bank is formed of light materials, and rests on a system of fascines.

Second Case. Sliding Embankments.

Embankments are sometimes executed in bad material, such as clay more or less charged with water, or which is easily saturated by rain, or where the earth has been greatly disturbed, and thus absorbs water more freely than in its natural state. Then the rapidity of execution so frequently required, is a fertile cause of bad construction; work is carried on, despite inclement weather, and mud or frozen earth is tipped on to the bank without hesitation. The employment of large earth wagons is also objectionable, because the material in falling assumes its natural slope, and tends to produce stratification. This is especially the case when the bank has a hearting, N, Fig. 38, formed with end-tipping wagons, while the side portions are completed by side-tipping. Besides the inequalities inseparable from constructing portions of the embankment at

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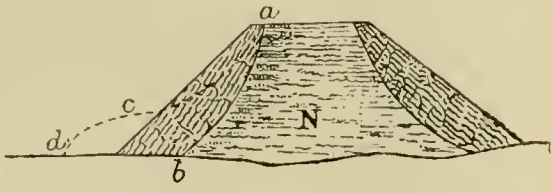
[1] *Vide* "Annales du Génie Civil," vol. iv. (1865), p. 217. Lallour, "Sur la stabilité et la consolidation des terrassements."

different times, and often with different materials, it may happen that sand, or even mud, may have been thrown on the line of junction *a b*, which produces a stratum of leakage, coincident with the natural slope. There can be no cause for astonishment, therefore, if the outer part of the bank falls in the direction *a c d*.

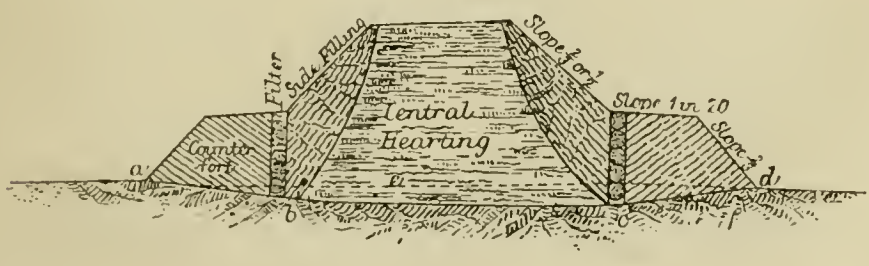
Fig. 38.



There are many prudent measures which should be adopted: to reject all saturated earth, to stop the works entirely during the periods of heavy rains, to revet with well-rammed earth embankments formed of clayey soil, &c. It is not possible in all cases to deposit the earth from barrows, nor to lay it in horizontal beds; these measures would be incompatible with economy and quickness in heavy works.

But, despite some addition to the cost, the work may be proceeded with as in the case of the Manchester and Bolton railway.[1] This work was commenced by two lateral zones, which formed counterforts or feet to the slope of the embankment. Then, as soon as these zones were sufficiently raised and consolidated, a central hearting was formed between them. In difficult cases it is necessary to take more precautions, and to construct the lateral zones as projecting counterforts, well bedded in the natural ground, and to execute them in stone, turf, or, more economically, in rammed earth, with inclined layers in a direction the reverse of the slope of the embankment. Thus an embankment constructed in the ordinary defective manner, with a central hearting and lateral prisms, may be thoroughly consolidated (Fig. 39) by the

Fig. 39.



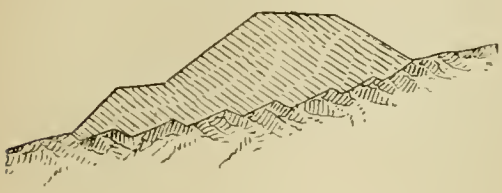
addition of counterforts of carefully-rammed earth, separated from the earthwork by a filter of broken stone, about 1 foot thick, or by

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 144.

a pile of superimposed gravel fascines. These filters keep away all water from the counterforts, which would otherwise drain into them from the embankment. It is preferable to execute these counterforts in advance with earth taken from the site, as at *a b c d e a*; by doing this they will have time to consolidate, and the proper slope can be given to enable them to stand until the filling-in is completed.

Plantations of acacias or of osiers contribute to the stability of sliding slopes. It is often useful to form, in the upper side, a lateral ditch, collecting the water of the slope, and carrying it off by a culvert, without which precaution it will collect at the base of the bank.

Fig. 40.



On side-lying ground an embankment may slip even if formed in good material; it is necessary therefore in such cases to trench out the natural surface (Fig. 40) in order to give the base sufficient hold.

The Repairs of Fallen Embankments.

When the slope of an embankment has fallen, it is advisable to remove the foot by short lengths (35 feet at the utmost), and to replace the excavation at once with well-rammed earth in horizontal layers, or in beds inclined the reverse way of the slope. The retaining counterfort thus established ought to be kept dry; and to effect this filter-walls of broken stone or gravel fascines should be placed between the new and the old work. If the weather be favourable, there should be no danger in using for the counterfort some of the upper portion of the fallen material, as it has been exposed to the action of the air, and may be rammed freely. The Villeneuve embankment (Mulhouse railway) fell for a length of about 250 feet, and was restored for the moderate sum of £53.

M. Bruère also repaired, at a cost of £58, the Vendeuvre embankment, for a length of 230 feet. Fig. 41 shows the arrangement adopted, from which it will be seen that a portion of the fallen material was left, being covered with a counterfort of rammed earth and new ground above, while the drainage was effected by means of a gravel filter standing in a brick channel.

On the Morcerf embankment (Paris-Coulommiers railway)

the filter is of broken stone, surrounded by matting. At some parts it was necessary to form two of these filters within the fallen

Fig. 41.

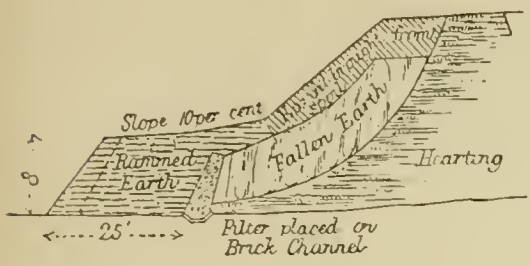
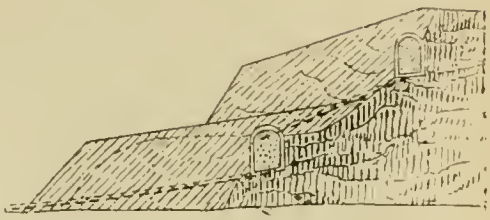


Fig. 42.

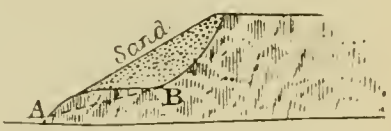


portion of the work (Fig. 42), connecting them together and with the outside of the slope by transverse drains. Two superposed counterforts retain the filters.

At the Villiers embankment, on the Paris and Mulhouse railway, the drainage consists of a dry stone wall, which at the same time helps to retain the bank. The fallen slope was restored to its original condition by means of ballast.

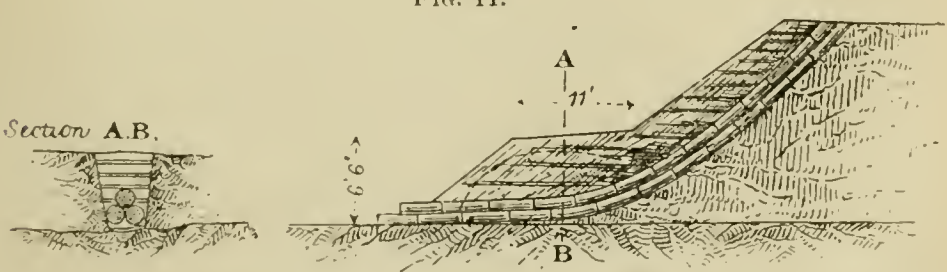
On the Main-Weser railway some clay embankments slipped and were restored with sand. The result of this was that pockets filled by sand saturated with water were formed, and these could not dry on account of the clay surrounding them. The drainage was effected by making channels, in which pipes were laid, as at A B, Fig. 43. These pipes were covered with broken stone to a depth of about 5 feet, to ensure their permanent action, in spite of further settlement.

Fig. 43.



On the Wissembourg railway the sides of failing embankments were drained by means of transverse trenches, in which were placed

Fig. 44.



gravel fascines (Fig. 44), afterwards covered with a facing of good earth, combined with the fallen material, and well rammed.

Slopes exposed to the action of water often require a protective stone covering, to prevent erosion. On the railway from Amster-

dam to Rotterdam, fascines are employed, combined with rubble-work, the whole being well secured.[1]

The preceding Notes have referred only to special difficulties encountered by engineers in the construction of earthworks for roads and railways, without considering many of the causes of landslips. The Author has recently (September 1874) submitted to the Institution a Memoir on the Action of Torrents, adding to it, as illustrative of his remarks, a notice printed under the auspices of the Canton of Vaud, on the ravages caused in 1873 by the Gryonne, a torrent of the Vaudoise Alps. These earth movements are referred to under the action of torrents and great waters, because such movements are often caused by them, although they appear remote; and it will be easily understood that if from this cause the foot of a hill has been shaken, large areas of cultivation may easily be lost. What is more curious, although belonging to the same cause, is that the works for draining marshes will often, under certain conditions and at a given moment, produce analogous accidents, with favourable results—the increase of the value of the land. For example, a short time ago some slips took place on the bank of the lake of Bienne (Switzerland), being the first results of the work of lowering the level of the lake, which is the same thing in effect as laying bare the foot of the slope which it bathes, since it deprives it of an existing counterthrust.

Since these Notes were written the Author has witnessed a disastrous landslip at Lausanne, in 1874, between the station and the town, due to the action of internal water, and at the termination of the construction of a cutting undertaken by the town for widening the railway. These works were conducted with but few precautions, in a soil where the utmost care was necessary, and where narrow headings ought to have been made, and retaining walls constructed. Whatever the cause, two houses of considerable value were destroyed, a large hotel in course of construction was so shaken that it must be taken down, and a new building which, owing to its resting on piles, resisted the shock for a considerable time, is now yielding. It is true that this latter is in the vicinity of a tunnel in course of construction, and it is difficult for the moment to judge either the actual cause or the comparative success that will be attained by the system of subter-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 179.

ranean galleries now being made to drain the soil, which consists of marl, clay, and sand. It would appear that the galleries have been driven a little too low; but it was supposed that if they were higher the inhabitants of the Rue de Midi would have been alarmed, and it is hoped they have nothing to fear. Careful investigations have been made, but the reports of successive Commissions have not yet been published. No doubt a litigious discussion will take place, on account of the large number of parties interested.

MEMOIRS OF DECEASED MEMBERS.

Mr. JOSEPH CUBITT, the only son of the late Sir William Cubitt, Past-President Inst. C.E., was born on the 24th of November, 1811, and died on the 7th of December, 1872. His father was the last survivor of that vigorous band of men, who not only raised themselves from a comparatively humble position to one of distinction, but who, in so doing, created a new profession—a profession to which, more than to any other, is generally attributed the credit of the rapid strides of civilisation and social improvement in the present century. With such an introduction to life, it was natural that Joseph Cubitt's attention should be turned to engineering in its various branches; and at the age of nineteen, having determined to follow his father's profession, he was placed with Messrs. Fenton, Murray, and Jackson, of Leeds, where Mr. Benjamin Cubitt, a brother of Sir William's, was then Managing Engineer. A fellow pupil writes of him:—"I well remember how assiduously and diligently Joseph applied himself to his practical education at the vice, the bench, the lathe, and in the drawing office. It was there, and in those departments, that our lamented friend gained the practical knowledge that so distinguished him in all his undertakings in after life."

After a period of two years' service in the workshops at Leeds, Mr. Cubitt returned to assist his father, the most important work in which he took a prominent and responsible part being the South-Eastern railway. On one occasion, being placed in the witness-box in committee on some other point, he was unexpectedly, and through an accidental circumstance, cross-examined on the whole of the estimates which he had assisted his father to prepare. This is a trifling incident; but to go through such a cross-examination well at his age, and with so little previous experience, was highly creditable to a young man.

Mr. Cubitt continued in his father's office as an assistant till the year 1843,—when he began his independent career. His most important work was the Great Northern railway, which, with its various branches, constitutes one of the leading lines of the country,

and the works of which are always acknowledged to have been well designed and well carried out.

Mr. Cubitt's other works included the branch of the South-Eastern railway from Ashford to Canterbury, Ramsgate, and Margate; the London, Chatham, and Dover railway, which, commencing with the East Kent in 1853, finally grew into the present extended system of main lines and branches; the drainage of the London Necropolis Company's estate, and the works for their Cemetery at Woking; Yarmouth Pier; the Oswestry and Newtown railway; Rhymney Valley railway; Weymouth Pier; Carmarthen and Cardigan railway, &c. He was consulted upon various other works, such as the Eastern Union railway project; the sea-wall and esplanade at Cove; on matters relative to the Pistoja and Vallée railway; the Direct Portsmouth railway, the project for which was carried on to the deposit of plans in 1846; the Llynvi Valley railway; on matters relating to Purton Pill on the river Severn, in connection with the Forest of Dean railway; and the Weaver Navigation. Mr. Cubitt was also much engaged in opposition to various bills in Parliament, and as arbitrator in disputes connected with engineering works.

His last great work was the new bridge at Blackfriars. It fell to Mr. Cubitt as the Engineer-in-Chief of the London, Chatham, and Dover railway, to carry out the extension of that line into the City of London in 1860. When the design for the railway bridge, to be built within 100 feet of the old Blackfriars Road Bridge, was submitted to the Bridge House Estates Committee, the question arose, as it was necessary that the piers of that structure should coincide with those of the long-talked-of new Road Bridge, whether the time had not arrived to remove old Blackfriars Bridge, long known to be both unstable and inconvenient. It was soon settled that a new bridge must be built, and the Bridge House Estates Committee called for designs from a selected number of eminent Engineers. That sent in by Mr. Cubitt was finally adopted and executed, and opened for public traffic by the Queen in person on the 6th November, 1869. The design was the joint work of Mr. Cubitt and Mr. H. Carr, M. Inst. C.E. Mr. Cubitt was anxious that his colleague's name should appear on the records of the bridge as joint Engineer along with his own; but that wish was overruled by the Bridge House Estates Committee, and Mr. Cubitt's name alone was placed on the official records, Mr. Carr remaining joint Engineer by private arrangement only. There is one point respecting Blackfriars Bridge which, in justice to its designers, should be put on record. No one can examine the

arrangement at the northern end without feeling surprise that the roadway of the Thames Embankment was not carried under the bridge and thence up towards Queen Victoria Street, thus avoiding the cross traffic of two main thoroughfares. In the first instance the instructions received from the Bridge House Estates Committee were to place the south abutment of the new design in the same position as the then existing abutment, but to advance the northern abutment into the river 120 feet, thus giving room to carry forward the embankment by a land arch under the roadway of the bridge. This arrangement was clear and natural, and the plans were prepared accordingly. Then came what was known as the "Battle of the Bridge." After a time the struggle took the form of "five arch" *versus* "three arch," and the advocates of the "five arch," including Mr. Cubitt, carried the day for the moment; but the "three-arch" party then got the position of the abutments altered to the shore line at both ends, thus making the bridge 180 feet longer than was at first arranged. Entirely new competitive plans were called for, giving a "three-arch" promoter the opportunity of converting his three-arch into a five-arch design. This was the origin of the now existing cross traffic at the north end of Blackfriars Bridge, and of the awkward shoulder to the embankment. Mr. Cubitt had commenced a Paper on Blackfriars Bridge for the Institution, but a claim by the contractors was, and is still, undecided, and as this claim involved questions which would have to be discussed, it was felt that it would not be right thus to anticipate the evidence to be given.

Mr. Cubitt's character and natural disposition were not such as to procure for him the prominence in the profession that he deserved. Being of a retiring disposition, "his natural diffidence kept him from pushing or asserting his proper place in the profession in which his talents would otherwise have placed him." His firm adherence, moreover, to the old line of practice threw him out of the stream of modern times; he never engaged in getting up schemes, but waited till called upon by those who required his services. This was the case even with regard to the London, Chatham, and Dover Railway Company. Though this trait of character did, no doubt, keep him in the background when he might have come forward, yet, on the other hand, combined with his well-known truth and honour, it gave great confidence in him in such matters as he did undertake. No one doubted his word or his strict justice; directors and contractors alike placed reliance on his decisions, whether acting as engineer on works carried out by himself, or as arbitrator in disputes between other parties.

Mr. Cubitt was elected an Associate of the Institution on the 14th of February, 1832, and was transferred to the class of Members on the 21st of January, 1840. He served as a Member of the Council from 1847 to 1855, was again elected in 1856–7, and continued in that capacity until December 1865, when he was made a Vice-President, and at the time of his death was the senior holder of that office.

Sir WILLIAM FAIRBAIRN, Bart., of Ardwick, Manchester. F.R.S., Hon. LL.D. of the Universities of Cambridge and Edinburgh, Corresponding Member of the Institute of France, and of the Royal Academy of Turin, and Knight of the Legion of Honour, was born at Kelso, in Roxburghshire, on the 19th of February, 1789. He died at Moor Park, in Surrey, the residence of his son-in-law, John Frederic Bateman, Esq., F.R.S., V.P. Inst. C.E., on the 18th of August, 1874, in his eighty-fifth year.

The Fairbairns were an agricultural family, settled on the banks of the Tweed for many generations, Sir William's mother, whose maiden name was Margaret Henderson, claiming descent from the ancient line of Douglas.

Though Kelso, in the south of Scotland, was Sir William's birthplace, in a district associated with the history and genius of Sir Walter Scott—the two men, one as a boy and the other as a young man, being acquainted with each other—his early years were, for the most part, spent in the Highlands. His father had removed from Kelso to the north at the request of Mr. Mackenzie, of Allan Grange, in Ross-shire, to take charge of the home farm, and act as general manager, or land steward, on the estate.

His uncle, Mr. Peter Fairbairn, was then commissioner for Lord Seaforth, and lived near Braban Castle; thus he was introduced to, and became acquainted with, the Seaforth family, whom he often visited as a much-esteemed and valued friend in after-life. It was here, at the parish school of Munlochy, that he received the principal part of his early schooling—limited, indeed, but sufficient to form the groundwork on which he afterwards built up a large amount of valuable knowledge by diligent self-culture; forming one of the many instances in which men, who have subsequently risen to distinction, have owed their early training to the Scotch parochial school system. It was here, also, that his love of mechanics was early manifested, for Fairbairn was no exception to the rule that bids one look for infantile traits of the talents that give a man distinction. When a child, his favourite playthings

were a knife, a gimlet, and a saw, with which he made tiny boats and ships without number, and water-mills and windmills by the dozen. One of his achievements was the construction of a wagon, in which he was able to wheel about a little brother who was too weak to walk. This brother, fifty years later, was the Mayor of Leeds, the late Sir Peter Fairbairn.

The family removed from Ross-shire to Newcastle-on-Tyne when young Fairbairn was about fourteen or fifteen years of age, his father having been appointed manager of the Percy Main Colliery. Previous to joining his family young Fairbairn had the advantage of some additional education with his uncle, who was parish schoolmaster at Galashiels, from whom he learnt book-keeping and land-surveying. At this time, in an early attempt to earn his own livelihood, he received an injury to one of his legs, which laid him up for several months. This period of confinement was, however, not lost, for the enforced leisure gave him the opportunity of much profitable reflection and useful study. But his best instructor in early life had been his mother, a woman of sincere piety, who, by example as well as by precept, opened the minds and hearts of her children, and whose character was of that quality which one is accustomed to hear of in the mothers of men so sterling and so remarkable.

At the age of sixteen, he bound himself apprentice to the owners of the Percy Main Colliery, where he began work under the charge of Mr. Robinson, the Engineer, at eight shillings a week wages, and remained till he was twenty-one. He was well prepared by home experience, and by mental and physical qualities, to make a great deal of the few opportunities which this situation offered. He had a hard life in many ways; and though he added to the family income by working overtime at various employments by which he could earn money, he devoted many evening hours to mental exertion, and drew up a regular time-table of studies and recreation, to which he adhered with wonderful steadiness. Thus Monday in each week was set apart for "mensuration and arithmetic;" Tuesday was relieved with "history and poetry;" Wednesday he indulged in "general recreation, novels, and romances;" Thursday was devoted to "algebra and mathematics;" Friday followed with "Euclid and trigonometry;" Saturday was like Wednesday; and Sunday was a day of rest, church-going, Milton, &c. Programmes like these have often been made, but have seldom been strictly adhered to; and one cannot but feel a tender sympathy for a man who, in his younger years, adopted and persevered in resolutions of self-culture which contributed so largely

to his subsequent successful achievements. While at Percy Main, he formed the acquaintance of George Stephenson, then employed at Willington Quay, near Newcastle; and the acquaintance ripened into friendship when both men had become distinguished.

On completing his apprenticeship at Percy Main in 1811, then a stalwart young man of twenty-one, he went to seek employment in London, accompanied by a friend and fellow-workman. They took their passage in a South Shields collier, and were nearly wrecked off Yarmouth in a terrific storm. Arriving in London, he applied for work to Mr. Rennie, the father of the late Sir John and Mr. George Rennie, and obtained it; but such obstacles were thrown in his way by the London mechanics' trade unions that he was obliged to leave. Speaking on this subject in after life, Mr. Fairbairn said: "When I first entered London, a young man from the country had no chance whatever of success, in consequence of the trade guilds and unions. I had no difficulty in finding employment; but before I could begin work I had to run the gauntlet of the trade societies, and after dancing attendance for nearly six weeks, with very little money in my pocket, and having to 'box Harry' all the time, I was ultimately declared illegitimate, and sent adrift to seek my fortune elsewhere. Laws of a most arbitrary character were enforced, and the unions were governed by cliques of self-appointed officers, who never failed to take care of their own interests."

Disappointed in London, he tried the country, and, in company with a fellow-workman from the North, obtained temporary employment in building a windmill near Hertford. When this job was finished they returned to London, where Fairbairn obtained regular employment at good wages; the principal establishment at which he worked being Penn's engineering works at Greenwich, where he made great progress in professional skill and knowledge. Work failing in London, he sought employment elsewhere, wandering through the towns of the West of England to Dublin, where he engaged with Mr. Robinson, of the Phœnix Ironworks, to construct machinery for making nails. The other workmen threatened to strike; and though their enmity did not frighten Fairbairn from making the machine, it frightened his employer from using the nails when made.

He was now again afloat, but attracted by the rising fame of its manufactures, his course was steered to Manchester, where in 1814, in his twenty-fifth year, he obtained employment as a working millwright under Mr. Adam Parkinson, with whom he remained two years, and until he began business on his own account.

In the same year, 1816, he married Miss Dorothy Marr, of Morpeth, whose acquaintance he had made five years before at Bedlington.

From this time a full account of Sir William Fairbairn's life would be, to a large extent, identical with a history of more than half a century of progress in mechanical science, in the development of the productive power of Manchester manufactures, in the application of iron to the building of ships, in the adoption of iron walls on land as well as on sea for purposes of military defence, and in a wide range of invention and discovery connected with the strength of materials of construction, and the economy of motive forces. Some of the greatest works of peace and war are associated with Sir William Fairbairn's name. The Britannia Bridge, over the Menai Straits, for instance, which is a wonder of the modern world; the Millwall shipbuilding works, which he founded and carried on for many years, till they were taken by Mr. Scott Russell; and, more recently, the iron forts of plates of great thickness and strength erected for purposes of national defence.

After commencing business, one of his first attempts to obtain congenial employment was to compete for a prize for a bridge over the river Irwell at Blackfriars, in Manchester. His design was for an iron bridge less costly and more elegant perhaps than the stone bridge preferred and erected. Another early design was for a conservatory and hothouse for Mr. Hulme, of Clayton, in which he was joined by an old shopmate, Mr. James Lillie, the commencement of a partnership which, under the name of Fairbairn and Lillie, subsisted for eighteen years. They began business in a small way, in 1817, by renting a shed at 12*s.* a week, and setting up a lathe for turning iron shafts, the motive power being supplied by a strong Irishman. Orders came in slowly, but it was from this commencement that one of the largest businesses, most intimately associated with almost every improvement in the mechanical arrangements connected with the cotton trade, was gradually developed.

The advantages resulting from previous thoughtful training upon the mechanical genius of Fairbairn soon exhibited themselves. In the joint career of Mr. Fairbairn and Mr. Lillie, the former, though not deficient in any way in mechanical skill and knowledge, was essentially the scientific projector, while his partner was the practical mechanic. It was not long before this happy combination bore the fruits which might be expected from it. The circumstances of the time and place were favourable. Cotton-spinning was in the early vigour of its development;

the mechanical contrivances by which it was carried on were clumsy, heavy, and unscientific. Some of the largest and most enterprising manufacturers were Scotch settlers, like Mr. Fairbairn, whose engaging manner and evident knowledge soon gained their confidence and orders. Messrs. Adam and George Murray, and Mr. John Kennedy, then a partner with Mr. McConnel, were amongst the largest cotton-spinners in the kingdom, and his earliest employers and patrons. Mr. Adam Murray commissioned Mr. Fairbairn to undertake the renewal of his mill machinery, an engagement which was satisfactorily fulfilled, though from the limited means of Fairbairn and Lillie, only by perseverance and energy. The gearing of the mill machinery which Mr. Fairbairn undertook to renew was, like all others of the time, of a primitive and clumsy description, liable to frequent breakages, often repaired on a Sunday. It was then the plan to transmit power from the engine to the machinery by heavy cast-iron shafts revolving slowly. Fairbairn perceived that by bringing up the speed at once in the engine, power would be gained, and that by substituting light round shafts of wrought iron in rapid revolution to transmit the power, the loss occasioned from the weight and friction of the cumbrous machinery then in use would be avoided. He thus diminished the weight and cost of machinery while quadrupling its power. His next step was the invention of the circular half-lap coupling, the adoption of which had an immediate effect on the expansion of the cotton trade, brought the inventor into notice, and laid, in fact, the foundation of his prosperity. Every mill-owner wished to have the advantage of multiplied power.

Thus, almost at a step, Mr. Fairbairn and his partner found themselves in the front rank of engineering millwrights. Orders came in faster than they could be executed. The firm had to remove to larger premises in Mather Street, where they first did the work by steam. This establishment was from time to time extended, till superseded by the erection of a manufactory in Canal Street, Ancoats, fitted up with the best machinery, for the execution of the largest contracts. He continued to improve cotton-spinning machinery in a manner similar to that already described, by which friction was lessened, and the speed was accelerated from 40 to above 300 revolutions per minute. It is, in fact, impossible to estimate the amount of development of the spinning trade which should be attributed to the genius and skill of William Fairbairn. These improvements reacted beneficially upon the silk and other textile trades which had been lagging behind the progress in cotton.

But his attention was not confined to cotton or silk-spinning machinery. In 1826–27, his firm fitted up the water-wheels for the extensive cotton-mills belonging to Messrs. Finlay and Co. at Catrine Bank, in Ayrshire.[1] In these wheels he introduced what has been called the 'ventilated bucket,' an arrangement by which the air confined in a bucket, instead of rushing back upon the water which was filling the bucket, quietly escaped by a false bottom, or open space, into the bucket above. The wheels at Catrine Bank are, even at this day, among the most complete hydraulic machines in Europe. About the time these were erected, Fairbairn and Lillie supplied the mill gearing and water machinery for Messrs. Escher and Co.'s large works at Zurich, in Switzerland.

Mr. Fairbairn's active mind did not allow him to rest satisfied with improvements in cotton-spinning and hydraulic machinery. His attention was turned to other matters of not less moment to this country; for they led to the general introduction of iron for ship-building.

In the year 1829 he was employed by the Forth and Clyde Canal Company to discover the best means of expediting the movement of canal boats. This led to an elaborate series of experiments, to determine the force of traction required for the attainment of various speeds on canals, and to ascertain, under what conditions and with what advantage, steam could be employed as the motive force in lieu of horse-power. On this subject he published an exhaustive report,[2] the result of which was the establishment upon canals of light iron passage-boats, travelling at a speed which at that time was not imagined possible. It was shown that the attainment of great speed on a canal occasioned a wave which moved the boats, if they could be maintained riding on this wave, and that then the power required for their traction became extremely small. This riding on the wave was accomplished by starting the boat at high speed, and was made available on many canals by 'fly-boats,' as they were called, for carrying passengers; but the system was gradually discontinued, as it was not suitable to all canals, and could not live against the greater speed of competing railways.

The question of canal traffic was, however, of little moment compared to the more important results of the experiments which

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. viii., pp. 45–66.

[2] "Remarks on Canal Navigation, illustrative of the advantages of the use of steam, as a moving power in canals, etc." By W. Fairbairn. 8vo. Plates. Manchester, 1831.

had been made. They directed Fairbairn's attention to the use of iron for ship-building, and no man has contributed more than he did to the practical development of this great branch of commercial enterprise. The first iron steamer was built by Mr. A. Manby, at the Horseley Ironworks, in 1821, and was called the "Aaron Manby." She was sent to London in parts, and put together in the Surrey Canal Dock. From thence she was navigated direct to Havre, and was employed on the Seine between that place and Paris. The next iron steamer was also built by the Horseley Iron Company, about 1824 or 1825; and shortly afterwards, Mr. Laird, of Birkenhead, commenced building them on a large scale. In 1831, Mr. Fairbairn built, in Manchester, a small sea-going iron vessel, which, though ten years later than the "Aaron Manby," was still one of the first constructed. It was carried through the streets to the nearest point at which it could be launched, and floated down to the sea. In 1833 or 1834 he built another in Manchester, and about the same time one in Selby for the Emperor of Russia.

In 1835 the partnership with Mr. Lillie having by this time ceased, Mr. Fairbairn was engaged by the millowners on the Upper Bann, in Ireland, to report[1] on the improvement of the water power of that river, by the construction of large reservoirs. In this he was assisted by Mr. Bateman, who subsequently executed the works.

In 1836 he erected extensive ship-building premises at Millwall, on the Thames, where he carried on business for nearly fifteen years, finally selling the property to Messrs. Robinsons and Russell, the latter gentleman building the "Great Eastern" in the same yard. During the time he occupied these premises about one hundred and twenty iron ships were built there, some of them of above 2,000 tons burthen. It was one of the earliest iron-ship yards in England, certainly the earliest of any magnitude, and its success led to the establishment of many others.

It was in this yard that the experiments on the strength of iron tubes were conducted, which led to the determination of the dimensions and proportions of the Conway and Britannia tubular iron bridges, and the law by which the power of resistance of wrought iron to compression and extension is calculated. The precise merit of Mr. Fairbairn in contributing towards the success of the great works just referred to, and his share in the execution, were for some time matters of dispute; but the names

[1] *Vide* "Reservoirs on the River Bann, etc." By W. Fairbairn. Tract. 4to. (vol. 6). Plates. Manchester, 1836.

of Robert Stephenson and William Fairbairn will be indissolubly connected with them, and they will long remain as monuments to the courage, the energy, and the ability of both. The facts of the case appear to be, that the idea of crossing the Menai Straits by a tubular bridge was due to Mr. Stephenson, who in 1845 consulted Mr. Fairbairn as to its practicability, and invited his co-operation. An experimental inquiry was decided upon, and the experiments were conducted, partly at Millwall and partly in Manchester, by Mr. Fairbairn, under the joint direction of Mr. Stephenson and himself. "There is no reason to doubt," says Mr. Smiles, "that by far the largest share of the merit of working out the practical detail of these structures, and thus realising Robert Stephenson's magnificent idea of the tubular bridge, belongs to Mr. Fairbairn." Professor Rankine says,[1] "Mr. Fairbairn acted along with Robert Stephenson in the planning and execution of the celebrated Britannia and Conway tubular bridges. The idea, which was first carried out in these bridges, of using hollow structures, through the interior of which the traffic should pass, was originally conceived by Stephenson. The discovery of the mode of construction by which that idea was rendered practicable, viz., a combination of rectangular cells, is due to Mr. Fairbairn, who has since erected more than a hundred bridges on the same principle."

Mr. Fairbairn very early directed his attention to the strength and other properties of wrought and cast iron, and his various recorded experiments have contributed more than those of any other individual to the accurate knowledge now possessed. He had the discrimination to engage in these investigations a mathematician of considerable ability, Mr. Eaton Hodgkinson, who, previously, was spending his mathematical power on comparatively useless objects. Mr. Fairbairn placed the works at his disposal, suggested experiments of practical value, and defrayed all the cost which attended them. In this way they worked for years together, Mr. Fairbairn directing the character of the experiments and Mr. Hodgkinson deducing mathematical laws and formulæ for calculations. The volumes of the Literary and Philosophical Society of Manchester, the British Association, and the Royal Society bear ample testimony to the extent, the interest, and the importance of these investigations.

In 1860 the Royal Society awarded him the Royal Medal "for his various experimental inquiries on the properties of the materials employed in mechanical construction, contained in the 'Philoso-

[1] *Vide* "Imperial Dictionary of Universal Biography."

phical Transactions,' and in the publications of other scientific societies." Major-General (now Sir Edward) Sabine, the Chairman of the meeting, in presenting the medal from the chair, after enumerating his various literary contributions to science, addressed to him the observations afterwards repeated by Lord Wrottesley: "Perhaps it may be said with truth that there is no single individual living who has done so much for practical science, who has made so many careful experimental inquiries on subjects of primary importance to the commercial and manufacturing interests of the country, or who has so liberally contributed them to the world."[1]

Nothing of practical value escaped Mr. Fairbairn in the use and application of his favourite material, iron. He invented, about 1836, the machine for riveting the iron plates of boilers, ships, and bridges. He improved the construction of boilers, and introduced the system of double flues and alternate firing, by which fuel was economised and smoke consumed. He turned his attention to the causes and the prevention of boiler explosions, in doing which he elucidated the law which governs the density and force of steam. He introduced an important improvement in the construction of boilers, the insertion of stiffening rings at short intervals internally, as he discovered, in the course of his researches, that the strength of a boiler was inversely as its length.

Mr. Fairbairn's professional occupations took him much abroad. In 1837 or 1838 he was in Russia, principally engaged there in connection with the Government cotton-mills under the direction of General Alexander Wilson, M. Inst. C.E. In 1850 he was again in that country, when he had lengthened interviews with the Emperor at St. Petersburg, to whom he presented his work on tubular bridges,[2] and from whom he received instructions to supply a design for a tubular bridge over the Neva. He was also in Sweden in 1850 and 1853.

In 1839 he accepted the invitation of the Sultan of Turkey to visit Constantinople, where he subsequently constructed manufactories for small-arms, and carried out many important works for the Government. On his return, he designed and built a corn-mill wholly of iron,[3] which, with its machinery, was sent out to Turkey and erected for Halil Pasha, the Seraskier of the Turkish army. This mill was probably the first iron house which had been built in England.

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[1] *Vide* "Proceedings of the Royal Society," vol. xi., p. 17.

[2] "An Account of the Construction of the Britannia and Conway Tubular Bridges." By W. Fairbairn. 8vo. Plates. London, 1849.

[3] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1843), p. 125.

In 1849 he visited Berlin for the purpose of laying before his Majesty the King of Prussia a design for the construction of a wrought-iron tubular railway and road bridge on the cellular principle across the Rhine at Cologne. This beautiful design forms the frontispiece to the second edition of his work "On the Application of Cast and Wrought Iron to Building Purposes," published in 1857–58. On this occasion he carried letters of introduction from his friend, Chevalier de Bunsen, to the distinguished author of "Cosmos," Alexander von Humboldt. The letters from Humboldt to Chevalier de Bunsen were published at Leipzig in 1869, and in a critique on these letters, which appeared in "Notes and Queries" (November 1869), is the following notice:—"Mr. Fairbairn had been recommended to Humboldt by Bunsen, then Ambassador at the Court of St. James's; and the 'celebrated man,' the 'creator of the gigantic tubular bridge,' was received with the utmost kindness by Humboldt as well as by Frederick William IV. Having had a long conversation with M. Von der Heydt, the Minister of Commerce, the latter accepted his (Fairbairn's) plans respecting the building of bridges. Frederick William invited him to dine at his table, and was charmed with him, as were all who came in contact with him. 'I cannot thank you enough,' Humboldt writes, 'for having caused me to become acquainted with this singularly remarkable, learned, estimable, gentle, and modest man.'"

In 1831 the British Association was established, at a meeting at York, by many of the most distinguished scientific men of the age. Sir William does not appear to have been one of those present on that occasion, but he very early joined the Association, and continued to be a constant attendant at its meetings, and a contributor to its reports and transactions. In 1837 he gave to the Association, at the request of the general committee, his first report on the strength and other properties of cast iron. Many of the early founders of the Association were his close and intimate friends. Amongst these may be mentioned (though few, alas! are still alive), Sir David Brewster, the Rev. William Vernon Harcourt, the late Lord Wrottesley, Mr. Hopkins, of Cambridge, Dr. Robinson, of Armagh, and General Sir Edward Sabine; with all of whom, and with many other great and distinguished men, he kept up the most friendly relations.

In 1861 he was the President of the Association at its meeting at Manchester. On this occasion, Lord Wrottesley, in handing over to Mr. Fairbairn the chair he had previously occupied, remarked:—"We may derive important instruction from the career of Mr. Fair-

bairn, whether we view him as the successful engineer, or as the distinguished man of science. In the former capacity he is one who has, by perseverance combined with talent, risen from small beginnings to the summit of his profession, and he forms one of that noble class of men, the Stephensons, the Brunels, the Whitworths, and the Armstrongs, who have conferred such important services on their country. It is extraordinary that any man should have been able, during the few leisure hours that can be snatched from an important and engrossing business, to accomplish for science what Mr. Fairbairn has done. Not only has he been a most successful contributor to mechanical science, but his liberality has been unbounded in placing all his great mechanical resources at the disposal of his fellow-labourers in the same field." [1]

He was a warm supporter of all societies having scientific education for their object. He co-operated with the late Dr. Birkbeck in the establishment of Mechanics' Institutions, and was one of the founders of that in Manchester, to which, in its early days, he acted as secretary, and devoted much time and attention. He was always ready to lend a helping hand to struggling societies all over the kingdom, and to promote the knowledge of others by imparting his own experience. This he did repeatedly by giving popular lectures on subjects of interest in the various matters which had engaged his own attention, and information on which he believed would be useful to others. The principal portion of these lectures was subsequently collected into three volumes, and published in 1856, 1860, and 1866 under the title of "Useful Information for Engineers."

On the occasion of the opening of the new buildings of Owens College, Manchester, in October 1873, he caught a severe bronchial cold, from which he never recovered, and to which, after a hard struggle, his robust constitution succumbed. This was his last public appearance.

To show the pertinacity with which, to the end, he devoted his time and talents to the service of others, it may be mentioned that it was his intention to have presided at a meeting of the Manchester Scientific and Mechanical Society on October 28th, 1873, though then in his eighty-fourth year and in feeble health, and for which he had prepared an address. That address, partly written after Sir William had been confined to his bed, was read by the Chairman of the meeting, Professor O. Reynolds, of Owens College. In it, his last work, attention was drawn to the im-

[1] *Vide* "The Engineer," Sept. 6, 1861.

portance of self-reliance and perseverance, and to the fact that in mechanical contrivances, as in all others, the nearer the unalterable truths of science were approached the more perfect would be the results. He mentioned several illustrations of the advantage to the arts and to manufactures that had resulted from strikes of workmen, which, however inconvenient at the time, had done good eventually, by compelling employers of labour to fall back on their own resources, and to execute work, formerly done by hand, by machinery and new inventions.

Sir William was an indefatigable writer, always ready to impart his knowledge to the public, and he had great facility in literary composition. He contributed many valuable Papers to the Literary and Philosophical Society of Manchester (of which society he was for a long time the President, occupying the chair which had been previously filled by no less distinguished a man than Dr. Dalton), the Manchester Geological Society, the British Association, the Royal Society, "Weale's Quarterly Papers," the "Encyclopædia Britannica," and many others. Among these are reports to the British Association—"On the Strength and other Properties of Cast Iron obtained from the Hot and Cold Blast" (1837); "On the Strength of Locomotive Boilers" (1853); "On the Mechanical Properties of Metals as derived from repeated Meltings" (1853); and "On the Tensile Strength of Wrought Iron at various Temperatures" (1856). In the Transactions of the Royal Society and other scientific bodies there are Papers on the Iron of Great Britain, on the Cohesive Strength of different qualities of Iron, on the Strength of Wrought-iron Plates and their Riveted Joints, and on the Temperature of the Earth's Crust, this latter being the result of delicate and interesting experiments carried on for many years in conjunction with the late Mr. Hopkins, of Cambridge, to ascertain the temperature at which liquefaction of metals and rocks under great pressure would take place, besides others of varied interest.

Amongst his larger works, in addition to those already mentioned, are: "On the Application of Cast and Wrought Iron to Building Purposes," 1854, of which new and enlarged editions were issued in 1858 and 1860; "Iron, its History, Properties, and Processes of Manufacture," 1861, extended and elaborated from an article communicated to the "Encyclopædia Britannica"; and "Mills and Millwork," 1861–3. His report on "Machinery in General," published in connection with the Paris Exhibition of 1855, should also be mentioned.

He became a Member of the Institution of Civil Engineers in 1830, and was also a member or fellow of most of the scientific

societies in Great Britain, and of many on the Continent. He received many decorations from abroad, and tokens of respect and esteem at home, and in 1869 her Majesty created him a baronet, in acknowledgment of his scientific attainments and services.

Hitherto this memoir has referred only to Sir William Fairbairn's character and progress as an engineer and a scientific experimentalist; but he was not more admired for these qualities than he was beloved for his social virtues. Affable and accessible, he was ever ready to communicate information and to give advice to all who sought it; buoyant and cheerful, he had the happiness to attract the esteem and affection of all with whom he came in contact. The moral of his life is the encouragement it affords to young engineers to steady perseverance and undeviating rectitude of conduct. He was an inborn gentleman in mind, taste, and manner, conscious of his own strength, and gratified by the approbation of others. He was, however, singularly modest and unassuming, and used to say, with characteristic self-depreciation, that "any man might do all that he had done, and more, if he would only study and work."

His remains were laid, on the 25th August, 1874, in the family vault in the churchyard of Prestwich, near Manchester, in which were interred three sons who had died before him. His funeral was attended by the corporate body, and by many sympathising townsmen; and so great was the number of people who crowded the line of procession to show their last marks of respect, that it became quite a public demonstration of sorrow. His memory will long be held in reverence and affection.

This memoir cannot be more fittingly closed than by the addition of a letter addressed by Sir Thomas Fairbairn (Sir William's son and successor) to George Evans, Esq., the Secretary to the Manchester Mechanics' Institution, in acknowledgment of a resolution of condolence conveyed by that Institution to the members of Sir William's family.

"Brambridge House, Bishopstoke,
Sept. 7th, 1874.

"Dear Sir,

"I have the honour to acknowledge your letter of the 4th instant, inclosing a copy of a resolution of the Board of Directors of the Manchester Mechanics' Institution, expressing their sense of the great loss which the institution has sustained in the death of Sir William Fairbairn. May I beg of you to convey to the board and to the members of the institution the sincere thanks of Lady Fairbairn, my mother, of myself, and of every member of the

family, for this most graceful expression of their feelings, and for their sympathy for us all in the time of our great sorrow? A mechanic himself, Sir William was, in its largest and truest sense, the friend of mechanics. He was a co-operator with Dr. Birkbeck in the foundation of Mechanics' Institutions; and you record with pride, which I may be permitted cordially to share, that the first prospectus of the Manchester Institution bore his honoured name. His whole life was a noble example to working men. He hoped that it might be so. He worked for good, unremittingly, unselfishly, and he accepted the honour, wealth, and reputation which were abundantly bestowed upon him, not in any boastful spirit, but as the rewards of honest labour. His works were labours of love, and I fervently pray that these, and his pure, simple, kindly nature, will keep his memory green in the hearts and affections of all that knew him.

"Believe me, my dear Sir,

"Very truly yours,

"THOMAS FAIRBAIRN."

SIR CHARLES FOX was born at Derby on the 11th of March, 1810, and was the youngest of the four sons of Dr. Fox, who held a prominent position as a physician in that town. He was articled to his brother, Mr. Douglas Fox, then practising as a surgeon, and remained with him for some time. During this period he prepared a great deal of apparatus with his own hands for his brother's lectures at the Mechanics' Institution, and also aided in working out the process of casting in elastic moulds, for which the silver medal of the Society of Arts was awarded to Mr. D. Fox. He manifested from the first much mechanical skill, and took the deepest interest, when quite a lad, in manufactures of all kinds. The projection of the Liverpool and Manchester railway gave increased force to his natural bent, and, being released from his medical articles, he was taken as a pupil by Captain Ericsson, then of Liverpool. Whilst with that gentleman, he was engaged in experiments upon rotary engines, and in designing and constructing the "Novelty" engine, one of the three which competed at Rainhill in October 1829. Shortly afterwards, through the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E., he obtained an appointment as an Assistant Engineer on the London and Birmingham railway, then in course of construction, being placed first under the late Mr. Buck, M. Inst. C.E., on the Watford section, and afterwards in charge of the Extension Works

from Camden Town to Euston Square. Whilst upon this railway he read a Paper before the Royal Institution upon the principle of Skew Arches. Upon the conclusion of his engagement of five years under Mr. Stephenson, he entered into partnership with the late Mr. Bramah, under the firm of Bramah, Fox and Co., and shortly afterwards, upon the retirement of Mr. Bramah, formed the manufacturing and contracting firm of Fox, Henderson and Co., of London, Smethwick, and Renfrew, who introduced improvements in the design and manufacture of railway plant, and especially of wheels, which they supplied in large quantities. During his connection with this firm, he was engaged upon some interesting experiments upon links and pins for suspension and girder bridges, the results of which were embodied in a Paper read before the Royal Society on the 30th of March, 1865.[1] He also introduced the switch into railway practice. The most important work carried out by him and his partner, Mr. John Henderson, was the erection of the building for the Exhibition of 1851 in Hyde Park. The work was commenced towards the end of September 1850, and the Exhibition was opened by her Majesty the Queen on the 1st of May, 1851. For his connection with this work Sir Charles Fox, together with Sir William Cubitt and Sir Joseph Paxton, received the honour of knighthood. Subsequently, he was employed to remove the building from Hyde Park, and to re-erect it, with many alterations and additions, at Sydenham, for the Crystal Palace Company. He also carried out during this period the East Kent, the Cork and Bandon, the Thames and Medway, the Portadown and Dungannon, the Lyons and Geneva (eastern section), the Maçon and Geneva (eastern section), the Wiesbaden, the Zealand (Denmark), and other railways. Amongst many large bridges, he executed those over the Medway at Rochester, over the Thames at Barnes, Richmond, and Staines, over the Shannon, over the Saöne, and over the Newark Dyke. The roofs of the Paddington, Waterloo, and Birmingham (New Street) stations, and also slip-roofs for several of the Royal dockyards were carried out by him. He also had a considerable share in the construction of the Berlin Waterworks.

From the year 1857, Sir Charles practised in London as a Civil and Consulting Engineer, in partnership with his two elder sons, Mr. Charles Douglas Fox and Mr. Francis Fox, MM. Inst. C.E. During this time he was Engineer to the comprehensive scheme of high-level lines at Battersea for the London and Brighton, the

[1] *Vide* "Proceedings of the Royal Society of London," vol. xiv., p. 139.

London, Chatham and Dover, and the London and South-Western railways, with the approach to the Victoria station, and the widening of the Victoria railway bridge over the Thames; to the Queensland, Cape of Good Hope, and Canadian (narrow gauge) railways; and, in conjunction with Mr. George Berkley, M. Inst. C.E., to the Indian tramway, the first narrow-gauge railway in India.

In the course of his professional duties Sir Charles met with a severe accident, which seriously impaired his health, and to this may, in a great measure, be traced his decease, which occurred at Blackheath on the 14th of June, 1874, at the age of sixty-four.

Sir Charles was elected a Member of the Institution on the 13th of January, 1838, having been proposed by Mr. George Lowe, and seconded by Mr. Robert Stephenson and Mr. Joshua Field. He was also a Member of various scientific societies. Until within the last few years, he was a frequent attendant at the meetings of the Institution, where his acknowledged professional standing, combined with a genial presence and the almost courtly deference with which he enunciated his opinions, always secured him an attentive hearing. Of his private life it will suffice to say that it was such as to claim the love and respect of all who knew him, whilst he performed all his duties as a man and a citizen with the most praiseworthy exactitude. It may indeed be said of him that rarely has there been a more generous man or a more tender and affectionate parent.

Mr. JOHN GRANTHAM, the second son of the late Mr. John Grantham, who was for several years engaged under the late Mr. Rennie in surveying many great works both in England and Ireland, was born at Croydon in 1809. After leaving school, he was engaged with his father in surveying various lines of railway then projected in England, some of which were eventually carried out. He also assisted in the establishment of steam vessels and an improved system of navigation on the canals between Dublin and Limerick, and in the employment of steam on the river Shannon, which system was subsequently taken up by the City of Dublin Steam Packet Company, and continued until the competition of railways diverted the traffic. Upon leaving Ireland, he, on the introduction of the late Mr. Charles Wye Williams, Assoc. Inst. C.E., with whom he resided in Liverpool, joined the late firm of Messrs. Mather, Dixon, and Co., of which he was subsequently manager and partner. In that establishment were constructed large mechanical

works, such as marine engines, locomotives, sugar-mills, and nearly every kind of machinery. In the year 1830 he gained the prize offered by the London and North-Western Railway Company for a design for drawing up, by means of stationary engines, the passenger carriages from Lime Street to Edge Hill Station, Liverpool, which engines are still at work for some purposes, though locomotive power has generally superseded them. Mr. Grantham was one of the founders of the Polytechnic Society at Liverpool, and continued an Honorary Member till his death.

The firm of Messrs. Mather, Dixon, and Co. having ceased to carry on business, he began practice on his own account at Liverpool as a Naval Architect and Consulting Engineer, and planned and executed several of the largest iron sailing and steam ships then employed in navigation, such as the "Sarah Sands," "Pacific," "Antelope," "Empress Eugénie," &c. He was Engineer to the Whitehaven Steamship Company and other companies, for whom he constructed vessels for Australia and Egypt. He took out several patents for screw propellers, which were then being introduced, and invented a system of sheathing iron-built ships with copper, which was afterwards employed by the Government, but without recognition or compensation. He held for some years the appointment of Surveyor of Passenger Steamships at Liverpool under the Admiralty, and subsequently under the Board of Trade.

In 1859 he left Liverpool for London, and was largely engaged in arbitrations and consultations in cases connected with insurance and casualties of the mercantile marine, and relating to the construction of vessels. He designed a fleet of steam colliers, which ply between London and the north of England. In connection with his brother, he, in 1860, became Engineer of the Northern railway of Buenos Ayres; and, in 1863, planned and executed the first tramway in Copenhagen, which is now working with success.

The latter part of his life was much occupied in the invention and perfection of a steam tramway car, which has been successfully tried, and for which he held a patent; but as the law of this country prohibits the use of steam carriages on public roads, except under such restrictions as to render their general employment impracticable, it has only hitherto been worked experimentally. In foreign countries, however, where no such impediments obtain, a field appears to exist for the employment of this machine, which is noiseless, and does not differ in general construction from the ordinary tramway car, while it can be worked at one-half the cost of horse power.

Mr. Grantham contributed many works to engineering lite-

rature, notably a memoir "On Iron Shipbuilding,"[1] and papers to several scientific societies. To the Institution of Civil Engineers he presented communications "On the Stationary Engines at the new Tunnel on the Liverpool and Manchester Railway,"[2] at Edge Hill; an "Account of some Experiments on a Vessel called the 'Liverpool Screw,'"[3] which he constructed; a "Description of the 'Vanguard' iron steam-vessel, after being ashore on the rocks in the Cove of Cork;"[4] "Description of the 'Sarah Sands,' and other steam-vessels, fitted with direct-acting engines and screw propellers, without intermediate gearing;"[5] and "Ocean Steam Navigation, with a view to its further development,"[6] which last embraced the most important features of an extended view of steam communication by sea, comparing the working of several vessels as to speed, expenditure of fuel per indicated HP., and discussing the bearing of the opening of the Suez Canal on ocean steam navigation. For this Paper he received a Telford Premium of books.

Mr. Grantham was one of the founders of the Institution of Naval Architects, in January 1860; he was placed on the Council, and remained there until his death. He communicated several Papers to the Institution, and took an active part in its management and proceedings.

Mr. Grantham was elected an Associate of the Institution of Civil Engineers on the 11th of February, 1840, and was transferred to the class of Member on the 29th of November, 1864. He latterly resided at Croydon, where he died on the 10th of July, 1874, at the age of sixty-five, deeply regretted by a large circle of friends, and universally respected for his exertions in support of the charitable and educational institutions of his native town.

Mr. THOMAS MARR JOHNSON was born at Appleby, in Lincolnshire, on the 29th of June, 1826. On leaving school, he was articled for four years to Mr. Dykes, surveyor, of Houghton, Yorkshire, and was afterwards engaged for two years, on his own account, in surveying and other works connected with the Fens of Lincolnshire. He then entered the office of Mr. John

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[1] *Vide* "Iron Ship-building: with Practical Illustrations." 8vo. 4to. Atlas of Plates. London, 1858.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 146.

[3] *Ibid.*, vol. iii., p. 71.

[4] *Ibid.*, vol. iv., p. 302.

[5] *Ibid.*, vol. vi., p. 283.

[6] *Ibid.*, vol. xxix., p. 126.

Fowler, Past-President Inst. C.E., with whom he remained until the year 1870.

Mr. Johnson early exhibited great ability and untiring energy, with considerable skill in design, and the closest attention to those details so important to success in engineering matters. He was, therefore, soon intrusted by Mr. Fowler with important works, including the Mid-Kent railway, the Farnborough Extension of the West End and Crystal Palace railway, the River Nene drainage and navigation, and the Norfolk estuary, river, and reclamation works. Between the years 1860 and 1869, he was, in conjunction with Mr. B. Baker, Assoc. Inst. C.E., exclusively occupied in carrying out, under Mr. Fowler's instructions, the works of the Metropolitan railway system, with the exception of a few months passed in the United States; and it was during these years that he developed fully the qualities which especially distinguished him in the professional circle in which he moved. These undertakings involved some of the heaviest and most complicated engineering works of the day.

In February 1870, Mr. Johnson left Mr. Fowler and joined the firm of Messrs. G. Smith and Co., builders and contractors. During the partnership, which continued up to the time of his death, this firm executed several large works, amongst others, the new Town Hall at Manchester, and Eaton Hall, Chester, the residence of the Duke of Westminster. He also, in conjunction with Mr. William Mills, M. Inst. C.E., superintended the design and execution of the new Holborn Viaduct Station for the London, Chatham, and Dover Railway Company.

Mr. Johnson was elected an Associate of the Institution of Civil Engineers on the 6th of April, 1852, and was transferred to the rank of Member on the 7th of February, 1863. He was also corresponding member of the American Society of Civil Engineers. He died on the 20th of July, 1874, at the age of forty-eight.

Mr. THOMAS LOGIN, F.R.S.E., was born at Stromness, in Orkney, in 1823. He was the youngest member of the family, and lost his father when a child, and his mother when only in his teens. Having a natural talent for Engineering, he was sent to Dundee, where he passed through a course of instruction, and obtained a practical knowledge by working at a factory. He went to India in 1844; his two elder brothers, who had been brought up to the medical profession, having preceded him. His eldest

brother, the late Sir John Login, who afterwards became guardian to H.H. the Maharajah Dhuleep Singh, was Residency Surgeon at Lucknow.

Having obtained an appointment in the Public Works Department, Mr. Login served for three years under the present Major-General Sir W. Baker. He was next engaged under the late Sir Proby T. Cautley in the construction of the Ganges canal, and took a leading part in establishing the works at Roorkee. Referring to this period, Sir Proby Cautley wrote:—

"Mr. Thomas Login, C.E., was under my orders in the Department of Public Works, North-Western Provinces of India, from the end of 1847 to April 1854, the date of my leaving India.

"Mr Login was employed during the whole of this time on most important works connected with mountain torrents situated between Roorkee and Hurdwar. Under his management the works at Dhunowri in connection with the Rutmoo torrent, and those for the passage of the Puttri torrent over the canal channel, were begun and completed—the latter, as connected with springs in which the flowings of the canal channel had to be laid 17 feet below their surface, was a work of extraordinary difficulty and engineering skill—the whole of the details having been carried out by Mr. Login with great success. To Mr. Login's advice and assistance, in fact, I consider that my design for the structure of this work was mainly indebted."

Mr. Login was engaged in Burmah till 1856, when he was invalided and came to England, where he remained till the autumn of 1857. On returning to India, he was appointed successively Executive Engineer of the Ganges and Darjeeling road, and of the Roorkee and Dehra roads. After this, he had charge of the Northern Division of the Ganges canal, and in that capacity his "fruitfulness in resources" was employed in arresting the progress of injury to the works of the canal, which at one time threatened to involve the necessity for laying out a large sum of money in repairs, or of entirely closing it. Although this course was recommended, it appears that, either from the measures taken by Mr. Login or from some other cause, the canal has continued to do its work and yield an important revenue up to the present time. After again being engaged on road works, and in charge of salt-works, he was removed to Sealkote in 1864, and made the surveys for a projected canal in the Rechna Doab. In 1865, he was transferred to Umballa, as Executive Engineer of the 7th division of Grand Trunk road. In 1868, he came to England, and gave much attention to the abrading and transporting powers of water,

having read papers on the subject at the meetings of the British Association both at Norwich and at Exeter. He also submitted to the Institution a Paper "On the Benefits of Irrigation in India, and on the Proper Construction of Irrigating Canals,"[1] for which he received a Telford Premium. If his life had been spared, he would have been permitted to carry out experiments on a large scale, with a view to obtain more certain data upon this important question.

The Suez Canal having been opened about the time of his return to India, he was ordered to visit it on his way out, and report upon it on his arrival. In passing through Egypt, he was much impressed with the mode of cotton cultivation practised there, which he considered had many advantages over that customary in India, and on his arrival at Umballa, he carried out some experiments on the ridge and furrow system, which apparently produced a much larger yield than the native broad-cast system.

Having been appointed Officiating Superintending Engineer at Umballa, he acted in that capacity for two years, and his appointment to that grade was confirmed in October 1873. His labours as Superintending Engineer of a large district were varied and onerous, and his health was failing; but he proceeded early in the following year to survey and report on the roads north of Simla. He had completed this survey, and was returning to his station, when an attack, in the valley of the Sutlej, of fever and paralysis ended in death, on the 5th of June, and his remains were interred at Simla on the following day. In Mr. Login the Public Works Department lost a talented officer of great experience, and upright and consistent in his conduct.

Mr. Login was a Fellow of the Royal Society of Edinburgh. He was elected a Member of the Institution of Civil Engineers on the 19th of May, 1868, and by the presentation to the library of copies of various reports showed the interest he took in its prosperity.

MR. WILLIAM RICHARD MORRIS, only son of Mr. Joshua Morris of Greenwich, was born on the 24th of October, 1808. He was articled to Mr. Charles Alexander Weir, Civil Engineer and Surveyor, and Manager of the Kent Waterworks, under whom he was engaged in making roads in the Grand Duchy of Mecklenburg Schwerin, in the erection of the Hammersmith Suspension Bridge,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 471.

and other works. He was afterwards employed by Sir W. Heygate to superintend the completion of the pier at Southend, one of the longest in the kingdom. Subsequently, he assisted the late Mr. T. G. Barlow in designing and erecting gasworks at Vauxhall, Lewes, Stratford-on-Avon, and other places.

In 1834, he made and published a complete survey of the parish of Greenwich; he was also engaged professionally by the Grand Surrey Canal Dock Company and Lord Lonsdale. In 1835, he was appointed superintendent of the Kent Waterworks under the late Mr. Thomas Wicksteed, M. Inst. C.E., Consulting Engineer; on whose resignation, in 1846, he was appointed Engineer to the Company. Under his advice and energetic management the works of the Company were at once greatly extended. In 1856, he reported that the river Ravensbourne, which had been the source of the Company's supply since 1688, could no longer be relied on to meet the increasing demands of the district; and he advised that wells should be sunk in the chalk which underlies the Company's works at Deptford. The supply of water from this source proved so abundant, and its quality so superior, that in the year 1863 the use of the water from the Ravensbourne was entirely abandoned. In 1864, the North Kent Waterworks Company was amalgamated with the Kent Waterworks Company, and to supply this additional district Mr. Morris sunk wells into the chalk at Crayford and at Shortlands, and from each point the Company are now pumping a large quantity of water. The total supply in twelve hours varies from 6,000,000 to 8,000,000 gallons, and is believed to be the largest quantity pumped from the chalk by any waterworks in England. Mr. Morris was no experimenting engineer, but he introduced many improvements in the general design and details of the sixteen pumping engines employed in the Company's works. He was the first to use the double-acting pump in combination with the single-acting Cornish engine for waterworks purposes, thereby avoiding the necessity of a standpipe. By the employment of surface condensers in combination with the engines, he was able, by passing the whole of the water pumped through the tubes of the condenser, to avoid the waste of the hot condensing water inseparable from the use of the injection condenser. On the passing of the Metropolis Water Act of 1871, he at once recommended the Company to proceed with the introduction of the constant supply to the smaller class of houses in their district.

In 1868, he experienced a slight stroke of paralysis, and though he rallied sufficiently to attend to his business engagements, towards the latter end of 1873 he became worse, and was advised to

leave the neighbourhood. This, however, he could not be prevailed upon to do, and on the 11th of January, 1874, he succumbed to a stroke of apoplexy.

The flourishing state of the Kent Waterworks, as compared with its position when he assumed the management, is the best proof of his ability. He was elected a Member of the Institution of Civil Engineers on the 1st of May, 1856, and was a Fellow of some other Societies.

Sir JOHN RENNIE, the second son of the late Mr. John Rennie, was born at 27 Stamford Street, Blackfriars Road, on the 30th of August, 1794. After receiving the rudiments of education at home he was sent first to Dr. Greenlaw's school at Isleworth, and subsequently to the celebrated Dr. Charles Burney, at Greenwich. On leaving the latter, in 1809, his father determined to train him for the engineering profession under his own eye. Sir John, accordingly, entered his father's manufactory at Holland Street, Blackfriars, and was there initiated into the minutest details of the profession, even to sawing planks, planing, and turning. From thence he passed to the drawing office, and was afterwards taught practical surveying by the late Mr. Francis Giles.

In 1813, having obtained a tolerable knowledge of his profession, Sir. John was placed under Mr. Hollingsworth, the resident engineer of Waterloo Bridge, the foundations of which he personally superintended through the severe winter of 1813–14. In 1815 the elder Rennie was appointed Engineer to the new Southwark Bridge Company; and, although nominating Mr. Meston resident engineer, he in reality confided the details to his son. On this occasion, Sir John, although a mere boy, was the first to introduce large blocks of Scotch granite from Portishead. With the exception of a short time employed with Mr. Giles in surveying the coasts of Scotland and Ireland, for the purpose of establishing a line of mail packets for the Government, between Portpatrick and Donaghadee, the superintendence of Waterloo, and particularly Southwark bridges, occupied Sir John until the opening of the latter, in 1819; after which Mr. Rennie, always anxious to promote his son's professional education in the widest and most liberal manner, sent him abroad, to afford him the opportunity of studying the works of ancient and modern engineers. How well young Rennie profited by the opportunities thus afforded him is attested by the note-books he has left, replete with drawings and descrip-

tions of various works, as well as by the knowledge he acquired of hydraulics, and his familiarity with the architectural and engineering works of the ancients.

On the death of the elder Rennie, the business was divided between his two elder sons, who remained in partnership as regards the works in Holland Street, but the principal part of the mechanical business fell to the late Mr. G. Rennie, M. Inst. C.E., while the completion of the engineering works devolved principally upon Sir John. The most important of these works was new London Bridge. The old bridge, which narrowed at once the traffic above and below its site, had long been condemned, and numerous plans had been formed at different times for its reconstruction, together with quays for the river banks. After long discussion, a design of the late Mr. Rennie was, in substance, approved of; and, on his death, Sir John was commissioned to carry it into execution. The original plan was almost entirely adhered to; but the determination of the Corporation to preserve the old bridge and its approaches, as a temporary means of communication, led to the construction of the present bridge slightly higher up the river, together with new approaches on either side. The disputes as to the bridge were numerous and violent, until the construction of what was simply a great convenience for the metropolis assumed almost the importance of a national struggle; and when a bill was required to give enlarged powers to the Corporation, consequent on the necessity for fresh approaches, five Cabinet ministers (the Duke of Wellington, the Premier, being in the chair) sat on the select committee of the Lords, and the session of Parliament was prolonged, in order to pass the bill. The new bridge was opened by his late Majesty William IV., in 1831, and Sir John received the honour of knighthood,—being the first of his profession since Sir Hugh Myddleton, similarly distinguished.

London Bridge was, however, but a part of the inheritance which Sir John had received. The completion of Sheerness Dockyard, of Ramsgate Harbour, and of Plymouth Breakwater also devolved upon him, in the capacity of Engineer to the Admiralty, a post in which he succeeded his father.

As regards Ramsgate, originally designed and commenced by Smeaton, and continued by the elder Rennie, Sir John completed the two outer piers, besides rebuilding the greater portion of the original structure. Over the breakwater at Plymouth he exercised a general superintendence, confiding the details and personal supervision to Mr. Whidbey; but he provided the berm on the seaward face, where additional strength was required against the

action of the sea. At Woolwich he executed a large dock, mast, and pond, now, with the rest of the dockyard, disused; also some minor works at Chatham. One of his leading works was the Victualling Establishment at Plymouth, of which the machinery was mainly designed by his brother.

At this time, and for many years afterwards, he was engaged on alterations and additions to Kingstown, Portpatrick, Portrush, Donaghadee, Warkworth, Sunderland, Hartlepool, Cardiff, and Whitehaven harbours, together with the enlargement of the Newry canal, several designs and reports for the harbours of the Isle of Man, the bridges at Staines, New Galloway, and over the Serpentine, the latter designed by the late Mr. Rennie.

In the drainage and reclamation of land, Sir John followed in the footsteps of his father, although he had not actually to carry out any specific designs. Among the works of this class may be mentioned the completion, in 1822, of the Eau Brink cut, near King's Lynn, by which a lowering of water of 7 feet was gained in the Ouse; the construction, in conjunction with the late Mr. Telford, of the Nene outfall below Wisbeach, which had the effect of similarly depressing the water-level by from 10 feet 6 inches to 11 feet, and which would have been still greater, had not strong opposition prevented the improvements being carried to the higher grounds at Peterborough, as was originally intended. These works were begun in 1826, and finished in 1831. Subsequently Sir John reported, for the Duke of Bedford, on the drainage of Whittlesea Mere and the surrounding fens, an area of 50,000 acres; but his plan, owing to the opposition of conflicting interests, was never carried into effect. In 1827–8 he restored the harbour of Boston, which, owing to neglect and bad management, had been nearly ruined, by forming a new channel, 1 mile in length, for a portion of the course of the Witham below the town. At an expense not exceeding £33,000, the navigation was so improved, that the town was accessible to vessels drawing 15 feet to 16 feet at spring tides, and from 12 feet to 13 feet at neaps. Besides the above, Sir John executed various improvements on the Welland; the effect of the whole being to improve the drainage of nearly 800,000 acres, and to reclaim 6,000 additional acres previously useless.

As may be imagined, Sir John, constantly employed on these works, so congenial to his tastes, could not fail to form some comprehensive plan for the entire district. Accordingly, when a committee of the leading landowners requested him to survey and report upon all the rivers falling into the Wash, he devoted a year to a thorough examination, not only of the rivers, but of

the Wash itself, and elaborated a scheme by which the navigation of the Nene, Ouse, Welland, and Witham would have been improved, the water lowered, and from 150,000 to 200,000 acres of land reclaimed from the sea. But this scheme appeared too great for realisation, and it was subsequently considerably reduced, and divided into two, of which the Norfolk Estuary Company proposed to reclaim about 40,000 acres, and the Lincolnshire Company a somewhat less amount. Eventually the opposition of the Lincolnshire landholders, who feared for their foreshore rights, led to the latter scheme being abandoned; while the Norfolk Estuary Company was so hampered by conditions and obligations, that, though still in existence, it has as yet inclosed but a very small portion of land. One benefit, however, was derived from their operations. The plan included a new channel for the mouth of the Ouse; this, the first work undertaken, besides greatly improving the port of Lynn, has been instrumental, in conjunction with the Eau Brink cut, in lowering the water in the Ouse to 11 feet below its former level. In spite of this failure, and two others somewhat similar in Holland and on the Essex coast, Sir John always upheld the feasibility and great value of these reclamations. He maintained that at least 600,000 acres in England and Scotland would amply repay the trouble and expense of inclosure, besides adding greatly to the permanent wealth of the country, and he has left in manuscript numerous suggestions as to the mode in which these may be effected.

In 1825-6 Sir John, in partnership with his brother, made his first contribution to railways by designing the Manchester and Liverpool line. Ultimately, however, the direction was conferred upon Mr. G. Stephenson. For this line the Messrs. Rennie, after a very careful investigation, decided that the gauge should be 5 feet 6 inches, a medium between the present broad and narrow gauges; but when the control of the works was conferred upon Mr. Stephenson, he adopted the old colliery gauge of 4 feet $8\frac{1}{2}$ inches, which, as the narrow gauge, has since become universal.

From that time until the great extension of the railway system in 1844–5, Sir John Rennie had but little to do with this branch of the profession, confining himself principally to hydraulics; and, though he prepared several bills, the lines were not carried out, but several have since been constructed on similar plans to those he proposed. It may here be mentioned that his principle in laying down a line was to make it as direct as possible, tapping the districts which lay on either side of the main line by nearly straight branches.

In 1852 he laid out a system of railways for Sweden, for which he received the Order of Gustavus Wasa; and three years afterwards, in 1855, he designed a series of railways and five harbours for Portugal, including a harbour of refuge for Oporto; none of which, however, were carried out, though he was subsequently commissioned to erect a breakwater at Ponte Delgada, at the isle of St. Michaels, one of the Azores, and the chief seat of the orange trade. For these services he received the Portuguese Order of the Tower and Sword. In 1861 he was invited by the Corporation of the City of London to submit competitive plans for the rebuilding of Blackfriars Bridge. In the succeeding year he reported to the Municipality of Vienna on supplying the city with water, and in 1862 he was Chairman of the Civil Engineering section of the International Exhibition. This was almost the last of his public acts; he shortly afterwards retired from the Norfolk Estuary works, and Ramsgate Harbour being acquired by the Government, he ceased to be the inspecting engineer. From this time he seldom appeared in public save at the Royal Society Club, of which he was remarkably fond. He occupied his leisure with the composition of several works, especially on hydraulics, which remain in manuscript.

The mechanical achievements, of which Sir John Rennie could claim a share, were mostly carried out in connection with his brother, the late Mr. George Rennie, M. Inst. C.E., to whose memoir reference may be made.[1]

Sir John Rennie might, in his declining years, have claimed the title of "Dean of the Faculty of Engineers." He stood alone, the last of a bygone race, a link connecting the Brindleys, the Smeatons, the Rennies, and the Telfords of the old system with the Stephensons and the Brunels of the new. His presidential address to the Institution in 1846 was a complete history of the rise and progress of the profession;[2] while the monograph on Plymouth Breakwater and, still more, his work on British and Foreign Harbours, for which he received tokens of honour from the sovereigns both of Russia and Austria, are no insignificant memorials of literary skill. He contributed the following Papers to the Institution:—"An Account of the Drainage of the Level of Ancholme, Lincolnshire;"[3] "On the Ancient Harbour of Ostia;"[4] and "On the improvement of the Navigation of the River Newry."[5]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 610.
[2] *Ibid.*, vol. v., p. 19.
[3] *Ibid.*, vol. iv., p. 186.
[4] *Ibid.*, vol. iv., p. 307.
[5] *Ibid.*, vol. x., p. 277.

In his retirement he addressed several letters to "The Times" on the drainage and improvement of land, and the storage of water and regulation of rivers. A letter on the management of the rivers and marshes of Italy having attracted the notice of Signor Sella, then premier, procured for him the Order of St. Maurice and Lazare.

It only remains to add that Sir John's acquirements extended much beyond his profession. Understanding several languages, he was extensively versed in general literature. He was long a Member of the Royal Society, and other scientific bodies; and was one of the first persons to whom Sir Humphry Davy applied when forming the Zoological Society.

Of his personal character one trait may be sufficient. Throughout his lengthened career, and in spite of the numerous disputes in which he was involved, he never bore a moment's envy or malice against any human being. His posthumous memoirs are full of the kindest notices of all with whom he came in contact; and whenever he had occasion to notice the Stephensons and their works, it is with a eulogy which their most devoted adherents might rival but could not surpass.

Sir John Rennie was elected a Member of the Institution on the 25th of June, 1844; he became President on the 21st of January, 1845, retaining the office for three years. He died at Bengeo, near Hertford, on the 3rd of September, 1874, just after completing his eightieth year.

Mr. JAMES RAINE RUSHTON was the second son of the late Edward Rushton, stipendiary magistrate of Liverpool. Having shown a strong natural aptitude for mechanics, he was, under the advice of the late Mr. James Walker, Past-President Inst. C.E., removed at an early age from the London University School, and placed as an apprentice with Messrs. Fawcett, Preston, and Co., mechanical engineers of Liverpool, with whom he remained for five years. He then entered the locomotive shops of the Liverpool and Manchester Railway Company, and obtained a thorough knowledge of locomotive work. Next he was for three years in the office of Mr. Edward Woods, M. Inst. C.E., who was then in charge of the old Liverpool and Manchester railway. On the amalgamation of the above line with the Grand Junction and London and Birmingham lines, Mr. Woods was appointed Engineer for the construction of new works on the northern division of the amalgamated lines; and Mr. Rushton

became his assistant on the extensions in Liverpool and the neighbourhood, which included the alterations of some of the existing tunnels, and the terminal passenger and goods stations. After this he was engaged as Resident Engineer of the Victoria Tunnel, under the town of Liverpool and the Leeds and Liverpool Canal, which connects Edge Hill Station with what was then the northern portion of the Liverpool Docks. That tunnel presents a fine example of masonry, the result of the constant and untiring supervision which Mr. Rushton exercised during its construction. About this time he was appointed one of the Admiralty Surveyors of Marine Steam Machinery. On the formation of the staff for the construction of the Egyptian railway, by the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E., Mr. Rushton was selected as one of the Engineers. He proceeded to Egypt in the autumn of 1851; and after the completion of the line entered the service of the Egyptian Government. In the year 1859 he was appointed a first-class Engineer on the Great Indian Peninsula Railway, and, on his arrival in India, became Resident Engineer of No. 16 Contract. While engaged in this capacity he made the acquaintance of Mr. Beddy, the Assistant Commissioner in charge of the town of Hurdah, a dirty and neglected place, under whose auspices Mr. Rushton planned and carried out a water supply and excellent municipal arrangements and striking improvements, and "Hurdah is now as perfect a little model town as can be found in India. . . . . The water scheme, 'Rushton Square,' and the 'Rushton Clock-tower' at Hurdah, will long remain to show the interest that Mr. Rushton took in all matters connected with the welfare of the people among whom he lived." For these services he received the thanks of the Chief Commissioner of the Central Provinces, in a letter dated the 23rd of June, 1866.

On the resignation of Mr. Graham, Mr. Rushton was selected, in July 1865, to fill his place as Chief Resident Engineer; and he entered upon the duties of his office on the 14th of September following. Soon after he succeeded to this responsible post, several of the masonry works showed signs of weakness or failed. To the onerous task of restoring these works Mr. Rushton successfully applied his experience and great engineering ability. In conjunction with the Company's Consulting Engineer he prepared the designs (as well as those of less important works) for the reconstruction of the Mhow-ke-Mullee and Towah viaducts. The latter, now known by the name of the "Alfred Bridge," was opened by the Duke of Edinburgh on the 9th of March, 1870, and has been designated, by those most capable of forming a correct opinion, "a magnificent

and unique work." It was pronounced by Mr. Turnbull, Engineer of the East Indian railway, to be by far the most striking work of railway masonry in India; and the Chief Commissioner of the Central Provinces declared his admiration of the excellence and beauty of the work, which would, he thought, in all probability, last for ages.

Mr. Rushton's connection with the Great Indian Peninsula Railway Company terminated in 1868; and in the same year, and about the same time, the agent of the company, General Rivers, also retired. Previously to their departure from India, a farewell dinner was given to them by the staff of the railway company and other gentlemen. On this occasion Mr. Rushton was presented with an address; and a sum of nearly £1,000, subscribed by the employés of the Company, was soon after forwarded to the Messrs. Elkington, in England, for a service of plate, the selection of which was left to Mr. Rushton.

With Mr. Rushton's arrival in England, in November 1868, his professional career closed. Eighteen years passed in Egypt and the East, with but two short intervals of repose, had told upon a constitution originally strong. He had long suffered from a painful affection of the throat, which ultimately terminated in bronchitis. He died on the 10th of June, 1873, in Liverpool, at the comparatively early age of fifty years. In his profession he was an honest worker; in his habits retiring and abstemious; and in the general relations of life he bore himself as a generous, temperate, and high-principled man. Of his skill as an Engineer his works give evidence; for his character as a man, the testimony of his friends.

Mr. Rushton was elected a Member of the Institution of Civil Engineers on the 4th of December, 1866.

Mr. JAMES SAMUEL was born at Glasgow on the 21st of March, 1824. He was educated at the High School of that city, and afterwards attended the classes for engineering by Professor Lewis Gordon at the Glasgow University. In April 1839 he was articled to Mr. Daniel Mackain, M. Inst. C.E., engineer of the Glasgow Waterworks, and subsequently held for three years the position of resident engineer at the Printing, Dyeing and Bleaching Works of his father near Glasgow, for which he designed and superintended the construction of the buildings, machinery, reservoirs, watercourses, &c. He came up to London, and was

appointed resident engineer of the Eastern Counties railway in January 1846, which position he held till June 1850. It was during his connection with this railway that, in conjunction with Messrs. Adams and Richardson, he brought out the fish-joint patent, to the improvement and development of which he devoted years of study and labour, and which, under various modifications, has been adopted on all railways. He likewise carried out numerous experiments on light engines and steam carriages on railways with the object of reducing the weight and cost of the rolling stock, with very satisfactory results.

Between the years of 1851 and 1858 he constructed successively the Morayshire, the Newmarket, the Llanelly extension, and Vale of Towy railways; also the new stone bridge over the river Avon at Evesham.

Early in 1858 he made, in conjunction with Mr. John Pitt Kennedy, M. Inst. C.E., the plans and estimates for the line of railway from Smyrna to Cassaba, and thence to Ushak, in Asia Minor, the former part of which railway has since been carried out by Mr. Edward Purser, M. Inst. C.E. In 1861 he went out to the United States to report upon and estimate for the completion of the Grand Rapids and Indiana railway, in the State of Michigan. He was then continuously engaged in inspecting and reporting upon various railways in Austria, France, Germany, and Russia. In May 1863 he accompanied a party of engineers to examine and report upon the feasibility of constructing a ship canal from the port of Greytown, on the Atlantic, up the river San Juan, and through the lakes of Nicaragua and Managua, to the bay of Tamarindo, on the Pacific Ocean; but, after a careful examination, he found that the cost of this route, as laid down by the French Engineers—from whose preliminary surveys the scheme originated—would be far in excess of that contemplated by the promoters, and the project was abandoned.

In the beginning of 1864 he was appointed, together with Colonel Talcott, joint engineer in chief of the Mexican railway from the port of Vera Cruz to the cities of Puebla and Mexico. Colonel Talcott retired from his connection with the line at the latter end of 1866. In 1871 and 1872 Mr. Samuel carried out a railway of 3 feet gauge in Cape Breton for developing the extensive coal mines in that region. In 1869 he exchanged the appointment of chief engineer to the Mexican railway for that of consulting engineer, a post he held till his death, which took place on the 25th of May, 1874, of paralysis, after an illness of three months.

Mr. Samuel was elected a Member of the Institution on the 5th of June, 1849. He was a man of good commercial acumen and sound judgment; but his temperament was very sanguine, and he was easily led. His taste for inventing amounted to a passion, and he was always taking out patents, as well as becoming interested in the patents of other persons.

Mr. THOMAS ALFRED YARROW was born in London in October 1817, and educated at the Military College, Sandhurst. In early life he was engaged under Mr. Edward Dixon, M. Inst. C.E., during the construction of the London and South-Western railway, and afterwards with his uncle, Mr. John Dixon, upon the construction of the Chester and Birkenhead railway. On the completion of the works, Mr. Dixon removed to Birmingham, and Mr. Yarrow was appointed Resident Engineer, which position he filled for some time, and, during the tenure of this engagement, designed and carried out the tunnel from the old terminus in Birkenhead to the Monk's Ferry. He then entered into general practice as an Engineer at Birkenhead, and was occupied in the design and execution of several important works, besides being frequently consulted upon some of the many schemes for the improvement of that rapidly-advancing district. Mr. Yarrow was subsequently appointed Surveyor and Bridgemaster to the County of Chester, when he designed and carried out several new bridges and other works for the county. In 1847, he retired from this position and made a professional tour on the Continent. On his return, he commenced to practise in London, and was engaged principally in connection with railways and sanitary works, among the latter being the purification of the sewage of the Fulham district by peat charcoal, which, so long as the works were in operation, was carried on successfully; a large quantity of the effluent water being profitably applied to the market gardens in the neighbourhood.

In 1856, Mr. Yarrow became Consulting Engineer to the Scinde Railway Company, and soon after to the allied companies, the Punjâb railway and the Indus Steam Flotilla. He manifested much energy and talent in the performance of the duties connected with these important appointments, taking charge of the construction in England of the iron bridges, engines, and machinery. Towards the close of the year 1861, failing health, arising from unremitting attention and anxiety, necessitated his retirement

from office; and he was succeeded by Mr. G. P. Bidder, Past-President Inst. C.E.

From this time the state of Mr. Yarrow's health no longer permitted him to pursue the active exercise of his profession, but he still continued to take a lively interest in everything connected with engineering, more particularly in what related to India; and he was a strong advocate for maintaining the 5 feet 6 inches gauge for at least the main and principal lines of railway in that country.

Mr. Yarrow's personal character was genial and warm-hearted, and although of late years the state of his health did not permit him to mix much in the society of his professional brethren, yet towards those who were associated with him in early life he continued to cherish the warmest friendship and to take a sympathising interest in their pursuits.

He was elected a Member of the Institution of Civil Engineers on the 3rd of February, 1857, and was at first a frequent attendant at the Meetings. He died on the 11th of September, 1874, in the fifty-seventh year of his age.

Mr. JAMES ALLAN, senior Managing Director of the Peninsular and Oriental Steam Navigation Company, was a native of Aberdeen, and whilst still a lad, entered as a junior clerk the engineering works of Messrs. John Duffus and Co., of that city. This firm, then recently established, was one of the largest in Scotland, and they opened and owned for many years a line of steamers between Aberdeen and London, building two vessels, the "Queen of Scotland" and the "Duke of Wellington," for the purpose. In 1832 a friendship sprang up between Mr. Allan and Mr. John Bourne, then commencing his engineering career at the same works, and when in 1833 the latter was transferred to Messrs. Caird and Co.'s, of Greenock, he induced his father, the late Captain Bourne, to give Mr. Allan employment as a clerk in the Dublin and London Steam Company's office in Dublin, of which company Captain Bourne was the director, and he and his brothers the chief proprietors. This was done with the concurrence of Messrs. Duffus and Co., who behaved in a very friendly way to Mr. Allan, and who considered that his opportunities for advancement would be greater in the new sphere thus opened. The company had a repairing shop at the North Wall, the books of which Mr. Allan kept. But as that duty alone did not afford him sufficient occupa-

tion, he also assisted the book-keeper at the company's chief office, Eden Quay. Mr. Morgan, the company's book-keeper, having suddenly died of cholera, Mr. Allan was the only other person who understood the books, and his efficiency in the performance of his duties led to his being appointed to the post.

About the year 1838, circumstances induced Captain Bourne to remove to London, and Mr. Allan accompanied him as his secretary and assistant. Captain Bourne's various undertakings had by this time become consolidated in an enterprise known as the Peninsular Steam Navigation Company, the parent of the existing Peninsular and Oriental Company. The Peninsular Company, in common with most new companies, disappointed expectation at first. The receipts were less than was expected; the expenses more. It was the first company which ran steamers to distant foreign ports, and would, under any circumstances, have been an arduous undertaking for a few private persons to carry out. Besides, the Messrs. Bourne, on whom the burden really devolved, were now past the prime of life, and from this, and various other causes, Mr. Allan's duties in London became of a very anxious and arduous character. They were, however, faithfully and successfully performed; and when in 1840 the Peninsular Company became a joint-stock undertaking, and extended its operations to Egypt, and finally to India, Mr. Allan became the Secretary to the new company. In this capacity he did not restrict his attention to technical duties, but practically acted as one of the managers, and had a large share in directing its policy. He often astonished his colleagues by the extent of his knowledge on engineering subjects, and in all such questions they soon came to defer to his opinion. He drew up a set of rules to be observed, and of duties to be performed, by every officer on board the different steamers—being probably the earliest example of such a code of regulations. He took the chief part in guiding the company to the adoption of oscillating engines, tubular boilers, and iron ships—then generally regarded as hazardous innovations—and all his recommendations turned out to be right; while they had the rare merit of being also early. No doubt he was aided in coming to these conclusions by his friend Mr. Bourne: but he had the valuable faculty of profiting by the knowledge of others, as well as by the results of his own experience and observations, and also of creating the disposition on the part of others to render him any service in their power.

At the time of the expansion of the Peninsular into the Peninsular and Oriental Company, the Transatlantic Company, established to trade across the Atlantic, and owning two steamers, the

"Liverpool" and the "United States," afterwards called the "Oriental," was simultaneously absorbed; and, in 1848, Mr. Allan was, by general consent, appointed a managing director of the Peninsular and Oriental Company. Subsequently, the two other managing directors died, and he thus became the senior, and so continued up to the time of his death.

In a life such as Mr. Allan's there are no romantic incidents to record, nor any startling achievements. His career was one of steady industry and intelligent supervision. Without marked energy either of intellect or of action, his progress was rendered sure by the wisdom of his judgments, which were singularly undisturbed by any emotion of interest or of temper, and by his amiability of character, which disarmed hostility. Large-minded and generous, above petty jealousies or suspicions, with a temper which could hardly be ruffled, and a patience which could hardly be wearied, he inspired a confidence not to be shaken, and won not merely universal esteem, but universal affection. Several years ago the employés of the Peninsular and Oriental Company raised, unknown to Mr. Allan, a subscription of £5,000 for a service of plate, which was duly presented with the sanction of the directors. Such testimony was hardly needed to show how much he was respected and beloved by the persons who had the best means of knowing him. Mr. Allan died, after a brief illness, at Camp's Hill, Lewisham, on the 15th of October, 1874, aged sixty-three. He was elected an Associate of the Institution of Civil Engineers on the 4th of December, 1849.

Lieutenant GORDON BIGSBY, R.E., the second surviving son of the Rev. Charles Bigsby, M.A., Rector of Bidborough, Kent, was educated at Marlborough College under Dr. Cotton, and received his commission in the Royal Engineers in 1858. After spending four and a half years on Government works at home, he in 1864 proceeded to India, and was appointed Assistant to the Superintendent of the Kurrachee Harbour Works. While serving in this capacity, he computed "Tide Tables of the Port of Kurrachee for the year 1865," for which he received the thanks of the Bombay Government. On leaving Kurrachee, he was nominated for special duty to report on the Anglo-Indian Telegraph in Arabia, Persia, and Beloochistan. In April 1866 he became Executive Engineer of Chanda, in the Central Provinces, and was complimented on the works by the local Government. In India,

where clerks of works do not exist, every plan, design, and estimate have to be prepared by the Engineer, or under his close supervision. In this department Lieutenant Bigsby won great credit, and was always reported on as "an officer of the highest ability and efficiency." After a short service as Executive Engineer in the Bengal P. W. D., Lieutenant, or rather Captain, Bigsby (he took the latter rank in India) in 1869 took charge of the works in the territories of the Maharajah of Bhurtpore. In 1873, having lost his health, he returned to England; but, unhappily, the disease engendered by residence in a tropical climate had taken too firm hold to be got rid of, and he died at sea on a voyage to Canada, at the early age of thirty-five. Lieutenant Bigsby was elected an Associate of the Institution of Civil Engineers on the 3rd of December, 1867, and always expressed regret that residence abroad prevented his taking an active share in its proceedings.

Mr. THOMAS GAUL BROWNING was born on the 5th of June, 1831. When fifteen years old he was articled to Mr. Ware, Architect and Builder, of Exeter, with whom he remained until he was twenty-one. During his pupilage he obtained a prize given by the Mayor of Plymouth for "the best set of drawings and plan for a gentleman's mansion," to be competed for by apprentices only. After a short service under Mr. Cummings, the late City Surveyor of Exeter, Mr. Browning in April 1853 came to London, and entered the office of Mr. Seth Smith, the eminent builder, of Pimlico, when he was chiefly occupied in superintending Government hydraulic works at Woolwich. About March 1855, he was appointed a clerk of works under the Metropolitan Commissioners of Sewers, and subsequently, on the formation of the Metropolitan Board of Works, became Assistant Surveyor of the parish of Marylebone. Such a position in one of the wealthiest and most populous of the metropolitan parishes, always one of great responsibility, became doubly arduous at this time, and required the most unremitting attention. The Metropolitan Railway Company was slowly burrowing a tunnel through the heart of the parish, closing streets, diverting sewers, undermining houses, and otherwise trespassing in a domain hitherto sacred to the parochial authorities. Simultaneously with these works, among the heaviest and most complicated in modern engineering, many miles of new sewers had to be built, besides the less onerous, but scarcely less important, work of maintaining the streets and roads in an efficient state. Mr.

Browning, however, gave such satisfaction in the performance of his varied functions that in March 1866, on the retirement of the Chief Surveyor, he was appointed his successor. He was one of the first to advise the employment of the steam roller and the snow plough in a metropolitan parish, and he devoted much time and thought to the perfection of a new fire escape, which was on the point of being introduced when its inventor was suddenly cut off in the forty-second year of his age, after a brief illness. Mr. Browning was much and deservedly respected in the parish of Marylebone as a most conscientious, able, and hardworking officer, who laboured early and late in the performance of his duty.

He was elected an Associate of the Institution of Civil Engineers on the 2nd of December, 1862, and died on the 30th of December, 1873.

Mr. CORNELIUS WILLES EBORALL was born in Birmingham in the year 1820. He was the son of Lieutenant Eborall, R.N., well known as manager of the Birmingham District Fire Office, and, subsequently, for many years the Goods Manager of the Grand Junction Railway Company, which post he retained on the amalgamation of that company with the London and Birmingham, now the London and North-Western Railway Company. Mr. Eborall received his early education in railway matters in his father's office. About the year 1847 he was appointed Goods Manager to the Sheffield Company, and succeeded Mr. James Meadows as General Manager of that line in 1849.

In 1850 he became the General Manager of the East Lancashire Railway Company, the fortunes of which at that time were at a very low ebb. Under Mr. Eborall, however, the property materially improved, and in 1858 it was amalgamated with the Lancashire and Yorkshire Railway Company upon equal terms. Mr. Eborall remained in that office until the year 1856, when he was appointed General Manager of the South-Eastern Company, under the Chairmanship of the Hon. James Byng, and subsequently of Sir Edward William Watkin, M.P., both of whom always entertained towards him the warmest feelings of personal friendship. His career during the last twenty years of his life was one of uninterrupted success. Filling a position the qualifications for which combined as much diplomacy as technical knowledge, Mr. Eborall's ability, special business aptitude, and conscientious zeal enabled him to overcome difficulties otherwise apparently insurmountable. His amiability of manner, his kind consideration for

the views and opinions of those who differed from him in the duties of official life, or who had to meet him as an antagonist, won for him, in railway circles, universal respect, and his appointment as arbitrator in the differences between the Caledonian and the North British Railways indicates the high estimation in which he was held by railway authorities outside the circle of his immediate business connections.

For a year before his death Mr. Eborall had been in failing health, and he had, in consequence, been absent from duty for some months. Towards the end of November 1873, he had, however, returned; but his strength was unequal to the demands upon it. On the 15th of December he was seized with an attack of apoplexy, and died on the following morning, at the offices of the Company, at the age of fifty-three years.

In Mr. Eborall, not only the South Eastern, but the entire railway world, sustained a great loss. Probably few men intrusted with the management of a great public undertaking succeeded more thoroughly than he did in enlisting the sympathies of the numerous body of officials and employés under his control, for the due performance of whose duties he was directly responsible, and who at the same time so entirely commanded the confidence and respect of the board, to whom the account of that responsibility had to be rendered. An anxious, constant, and earnest watchfulness over the matters in his charge marked his whole career, and the evidence which all his acts furnished of this thorough devotedness to duty not only stimulated those around him to a strict performance of their respective duties, but naturally created through the entire staff a feeling of common and deep interest in the general welfare and success of the undertaking. His manner was invariably pleasant and courteous; nor did he hesitate in all matters of importance to ascertain personally the views, and seek the assistance and co-operation, of the officers of the company, listening with attention and respect to whatever counsel might be offered, and evincing a consideration and deference for the frank opinions of those who tendered their suggestions or advice.

Although not perhaps a man of great originality of thought or idea, Mr. Eborall nevertheless displayed a quick apprehension of the leading features of a case, and an unusual clearness of perception in seizing on any point of value, or in the discovery of a weak part in a subject submitted to him. His perseverance and tact were remarkable in tracing out the facts and bearings, and in thoroughly mastering all the difficulties, of a complicated business, weighing the various opposing arguments with a diligence and

acuteness which necessarily tended to render his decision just and conclusive beyond dispute.

In the selection of servants Mr. Eborall possessed a peculiar power of discernment, as regards the capabilities of men, and their fitness for particular positions. In the exercise of his authority, although disposed to leniency, he was a strict disciplinarian, and required from all an exact performance of the task assigned to them. He never overlooked any instance of neglect, or other fault, which may have endangered the safety of passengers.

In the earlier days of his appointment to the South-Eastern Company, Mr. Eborall devoted himself with great energy and success to the abolition of the active and mischievous competition which had prevailed for years between his own and neighbouring companies; and, as regards the then growing railway communication with the Continent, he applied himself to the introduction of useful measures and improvements, both as to the passenger and merchandise traffic, and succeeded in removing many serious inconveniences and hindrances in the service, thus tending materially to the benefit of the companies, as well as to the comfort and advantage of the travelling public. A conviction of the necessity for a West End communication with the existing system of the South-Eastern Railway Company urged him to take a prominent part in the promotion and furtherance of the Charing Cross and Cannon Street extension lines, and the success which attended his untiring efforts to insure the safe and regular working of the difficult service on these lines, when opened for traffic, bears high testimony to Mr. Eborall's practical abilities as a railway manager.

Mr. Eborall was elected an Associate of the Institution of Civil Engineers on the 5th of December, 1865, and frequently joined in the discussion on Papers connected with the working of railways. He was also a Lieutenant-Colonel in the Engineer and Railway Volunteer Staff Corps, and took an active part in solving the problems submitted to that body by the War Office.

Mr. THOMAS GRISSELL was born in London on the 4th of October, 1801, and was educated at St. Paul's School. He had been intended for the medical profession, but was in 1815 articled to his uncle, the late Mr. Henry Peto, the builder, and became his partner in 1825. On that gentleman's death, in 1830, Mr. Grissell was joined by the present Sir S. Morton Peto, Bart., in conjunction with whom, for many years, he carried on one of the largest building

and contractors' businesses in the kingdom. When Sir S. Morton Peto became Member of Parliament for Norwich, the business connection ceased.

Mr. Grissell was elected an Associate of the Institution on the 7th of March, 1843, and served on the Council in that capacity in the year 1845. Having constructed, under Mr. Wyatt, the Society's former lecture-room, &c., in the autumn of 1846, he was a considerable donor to the funds of the Institution in respect to his charges for the work.

He executed the improvements in the Severn navigation, under Sir William Cubitt, Past-President Inst. C.E. Also a great portion of the Great Western railway, including the viaduct at Hanwell, under Mr. Brunel, Vice-President. Inst. C.E. Much of the South-Eastern railway, under Mr. Joseph Cubitt, Vice-President Inst. C.E.; and was largely concerned for the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E. He was the builder of the following public buildings in London:—The Reform, Conservative, and Oxford and Cambridge Club Houses; the English Opera and French Theatres, Hungerford Market, the Nelson Column, and last, but not least, the new Houses of Parliament, under Sir Charles Barry. He was a Fellow of the Society of Antiquaries, a Member of the Royal Society of Literature, and a Fellow of the Horticultural Society.

In 1850 he retired from business, and purchased Norbury Park, near Dorking. He was in the Commission of the Peace for the county of Surrey, and served the office of High Sheriff in 1854 and 1855. He died on the 26th of May, 1874.

Mr. JAMES ARCHIBALD HAMILTON HOLMES, eldest son of Lieut.-Colonel J. G. Hamilton Holmes, late 12th Royal Lancers, was born on the 13th of January, 1836, at the Royal Military College, Sandhurst, where his father was a student in the senior department. His education, begun at home, was completed at a proprietary school at Blackheath. Mr. Holmes passed for the Royal Military Academy, Woolwich, but ill-health prevented him continuing at the Academy, and he matriculated at Trinity College, Dublin, and articled himself to Mr. Hemans, Vice-President Inst. C.E., by whom he was employed on railways in the north of Ireland. He next was appointed an Assistant Engineer on the Recife and São Francisco railway, from Pernambuco to the interior of Brazil, where he served three years, returning to Eng-

land in 1862. In the same year he went to India, as Assistant Engineer, for the Madras Irrigation and Canal Company, where he remained until the temporary suspension of the works in 1866. On the resumption of the works, Mr. Holmes was again sent to India by the Madras Irrigation and Canal Company, and continued in the service of this company about three years, being mostly employed in surveying and levelling, part of the time in Mysore, in independent charge. On the reduction of their working establishment, he for a short time was employed on the Carnatic railway, from which he was appointed to the Department of Public Works of Ceylon, and died of fever at Batticaloa, Ceylon, on the 17th of January, 1872. Mr. Holmes was elected an Associate of the Institution of Civil Engineers on the 7th of February, 1871.

Mr. JAMES INNES HOPKINS, the fourth son of Mr. John Castell Hopkins, of Kingston-on-Thames, was born in Edinburgh in October 1837. After completing his education he entered the business of Messrs. Snowdon and Hopkins, afterwards Hopkins and Co., of Middlesborough. Although, in the twenty years of his active business life, he was more concerned in the commercial part of engineering than the purely mechanical processes, he still was conversant with most of the details of iron-making and its various branches. In April 1865, Messrs. Hopkins and Co. and Messrs. Gilkes, Wilson, and Co. united under the joint name of Hopkins, Gilkes, and Co., Limited. Mr. James Hopkins was an active and energetic member of the new directorate, subsequently representing the company in London, where he was well known and deservedly esteemed as the resident director. His genial disposition, unfailing *bonhommie*, and ability in matters of business, gave him a place of much esteem in the trade. In the latter part of 1873 his health began to fail, and early in 1874 he went to Pau for change and rest; but, on his homeward journey, he died at Paris on the 22nd of May, 1874. Mr. Hopkins was elected an Associate of the Institution of Civil Engineers on the 1st of February, 1870; he was also a Member of the Institution of Mechanical Engineers, of the Cleveland Institution of Engineers, of the Iron and Steel Institute, and of other kindred associations. He was Captain in the 1st North Riding of Yorkshire Volunteer Artillery, and had served in the Town Council of Middlesborough.

Mr. SAMPSON LLOYD was born in Birmingham on the 7th of June, 1808. He was the seventh son of Samuel Lloyd, banker, of that town; and was brought up at schools connected with the Society of Friends at Kendal, his mother's native place, and afterwards at Tottenham. At a comparatively early age he was apprenticed to his brother at Stockton-on-Tees. Subsequently he was employed in his father's bank in Birmingham, until, on the death of one of his brothers, he took an interest in a colliery property at Wednesbury, which had belonged to the family for several generations. This led to the establishment of the firm of Lloyds, Fosters, and Co., in 1835, in which he held a fourth share. The object of the company, in the first instance, was to develop the colliery above referred to, by building blast-furnaces and introducing improved winding and pumping machinery. In connection with the furnaces was a small foundry and engineering establishment, of which Mr. Sampson Lloyd undertook the management. As the railway system began to increase, his attention was turned to the manufacture of railway material. In this he was assisted by the late Mr. John Joseph Bramah, to whom he always considered that he was indebted for his first start in this branch of the trade. Under his energetic management the business rapidly developed, and the Old Park Ironworks became one of the first establishments in the kingdom for the manufacture of wheels and axles, and other railway material. In 1856 large rolling mills were erected for the manufacture of tires and axles, and this for many years was a most successful branch of the company's business; to which was added, about the year 1867, works for the manufacture of Bessemer steel in all its branches. In January 1867 the business of Messrs. Lloyds, Fosters, and Co. was transferred to the Patent Shaft and Axletree Company, Limited, of which company Mr. Sampson Lloyd became vice-chairman, and he continued in the management till within a year of his death, which took place on the 26th of September, 1874, at Areley House, near Stourport, where he had recently gone to reside.

Mr. Lloyd was always foremost to adopt any invention which was sufficiently developed to be applicable to his business. The firm was among the first in the South Staffordshire district to introduce the hot blast in their furnaces, to utilise the waste gases for various purposes, as well as to introduce the improvements of the late Mr. Joseph Beattie, M. Inst. C.E., and Mr. Mansell, in the construction of railway wheels. Numerous important contracts for bridge-work were carried out under Mr. Lloyd's superintendence for the Indian, Spanish, and Australian railways. One of

the largest works with which he was immediately connected was the new Blackfriars Bridge, for which the firm supplied the iron-work. That part of the contract was executed without difficulty but being guarantors for the other contractors, and unusual difficulties being met with in forming the foundations, much anxiety and annoyance were experienced by Mr. Lloyd, to whose perseverance and energy it was mainly owing that the contractors were enabled to complete the work.

Mr. Lloyd was elected an Associate of the Institution on the 7th of April, 1857. He took a leading part in the establishment of the Institution of Mechanical Engineers, and was an active member of the council of that society for ten years, and was one of the vice-presidents from 1864 to 1872. He was chairman of the Darlaston Steel and Iron Company, and much interested in the development of the company's property during the latter years of his life; also chairman of the South Staffordshire Waterworks Company and of the Swansea Wagon Company. Both of these companies were in a state of great depression when he took the office, and to his energy and perseverance their present prosperous position is chiefly due. During the greater part of his life Mr. Lloyd avoided public affairs, except in immediate connection with the town of Wednesbury; but after leaving that place, and taking up his residence at Wassell Grove, Hagley, he became a magistrate for the counties of Staffordshire and Worcestershire.

Mr. Lloyd was a man of great energy and perseverance, of a kindly disposition, ever ready to sympathise with the sorrows and difficulties of others, whether poor or rich. In public affairs, in business, and in private life, the same good traits were manifested in little things as well as in more important ones, always combined with characteristic warm-heartedness and cheerfulness. He was much esteemed and beloved by his family and workpeople, and all those connected with him in his various undertakings.

Sir HARRY STEPHEN MEYSEY-THOMPSON, Bart.,[1] late Chairman of the North-Eastern Railway Company, was the eldest son of Mr. Richard John Thompson, of Kirby Hall, near York, and was born at Newby Park, Yorkshire, on the 11th of August, 1809.

[1] A biographical sketch of Sir H. S. Meysey-Thompson, by Earl Cathcart, appears in "The Journal of the Royal Agricultural Society of England," Second Series, vol. x., pp. 519–541. From a pamphlet descriptive of his career "as a man of business" (printed for private circulation only in 1874, and of which a copy has been presented to the Library of the Institution), several passages have been extracted and incorporated in this notice.

As a child his health was delicate, and he was in consequence educated at home, or under private tuition, until he went to Cambridge in 1828. Although he was by no means what is called a "reading man" at the University, he established among his contemporaries the reputation of a man from whom good work was to be expected in after life. The anticipations thus formed were amply fulfilled, and if his name is not so widely known as that of others of his generation, few have excelled him in a career of usefulness. On leaving Cambridge, he employed himself in completing his education, and for that purpose spent some considerable time on the Continent, until he finally settled down, some years before his marriage, in 1843, to farming occupations upon the family estate in Yorkshire, at that time in his father's possession, but to which he succeeded in 1853. The improvements which he effected there can only be appreciated by those who have had an opportunity of comparing the Kirby Hall property as it is now with its condition thirty years ago. Lands and park, and even the house itself, are altered beyond recognition, save by those who have known them the most intimately, and who have themselves witnessed the beneficial changes produced by the hands and skill of one who was indeed a master.

In 1838 began Mr. Thompson's connection with the Royal Agricultural Society. The society may almost be said to owe its existence to the combined efforts of Mr. Thompson and the late Mr. Pusey, and its Journal has been enriched by many of their contributions. Mr. Thompson's last paper, which appeared in 1872, "On the Management of Grass Land, with especial Reference to the Production of Meat,"[1] is particularly valuable, and has been published separately. To Mr. Thompson is largely due the discovery of the power inherent in the soil of absorbing and assimilating ammonia. The guiding idea flashed upon him when observing the escape of ammonia from manure heaps. In conjunction with the late Mr. Joseph Spence, of York, Mr. Thompson experimented as follows: A glass tube was filled with ground turf to represent a 4-feet section of earth. A solution of ammonia was applied at the top, and the percolation noted. The result was fairly startling; it was not filtration, but a new chemical action. In the volume of the Journal of the Royal Agricultural Society for 1850,[2] Mr. Thompson gives a modest account of this discovery;

[1] *Vide* "The Journal of the Royal Agricultural Society of England," Second Series, vol. viii., p. 152.

[2] *Vide* vol. xi., p. 68, "On the Absorbent Power of Soils." By H. S. Thompson.

but its importance can scarcely be overestimated. In the words of a great living authority, "It is remarkable that this slight experiment contains the germ of what I consider to be one of the most important, if not the most important, of all the scientific investigations connected with the practice of agriculture."

But the most interesting part of Sir Harry's life, as far as the general public is concerned, is that which was spent in the service of the North-Eastern Railway Company. He must ever be identified with the prosperity of that line, the third of the great English railways in point of size, and the first in point of success. In 1849 he was elected Chairman of the York and North Midland Railway Company, which was at that time unable to pay any dividend. For five years Mr. Thompson devoted a large portion of his time to this company's affairs, and while the results of his labours were most satisfactory to his constituents and honourable to himself, there can be no doubt that he was being educated for filling the much more onerous and responsible post of Chairman to the North-Eastern Railway Company, to which he was elected shortly after its formation in 1854. In all the weighty and delicate negotiations which resulted in that important union between the principal railways in the north-eastern district of England, Mr. Thompson, as the chairman of one of the associated companies, necessarily took a leading part. For twenty years he was chairman of the resulting North-Eastern Company, and during the whole of that period, until failing health compelled him to relax his labours, he watched over and superintended all its affairs with the most unflagging devotion, and with consummate skill, discretion, and ability. Few companies have been more fortunate in their chairman than was the North-Eastern in Mr. Thompson; and that the shareholders were conscious of this is evident from the fact that never, on any occasion during his chairmanship, did they fail to adopt any proposition which he put before them.

Under Mr. Thompson's presidency the North-Eastern Company grew and prospered. Further unions were effected with other companies in the district, involving many prolonged and difficult negotiations, in all of which he took the principal share; so that when he resigned the chair, the company possessed intact a territory stretching from the south of the Humber to the Tweed. As compared with its origin in 1854, it had much more than doubled in capital, mileage, and resources, and was then yielding to its proprietors a dividend larger than was paid by any other leading railway company in the kingdom, and greater, probably, than in

his most sanguine moments he had ventured to anticipate. The company has not been backward in recognising these great services. A magnificent testimonial was voted to him on his retirement, and, though he did not live to enjoy its presentation from the hands of so many of his oldest friends, he was yet enabled to see and admire in private the splendid fruits of their gratitude.

"But Mr. Thompson did not confine himself in railway matters to the North-Eastern Company alone. As the railway system extended, and the relations between companies became more and more complicated and conflicting, and the attention of Parliament and the public becoming at the same time more closely directed to railways and their regulation, he saw the necessity for some bond of union being formed amongst them, with the view of promoting internal harmony, and of taking measures for the protection of their common interests, more especially against hasty or hostile legislation. Accordingly, he suggested, and in 1867 ultimately organised the Railway Companies' Association, consisting of representatives from all the railway companies in the kingdom who chose to join it. All the leading, and many of the smaller companies, did join the association, and Mr. Thompson was unanimously elected their Chairman, which office he held until compelled by the state of his health to resign it, in 1873. That he should have been considered worthy to preside over an association composed of the ablest and most thoroughly disciplined administrators in the railway world, sufficiently shows the opinion which was entertained of his character and business abilities; and on accepting his resignation, which the association did with deep regret and sympathy, a resolution was unanimously passed, recording 'their high estimate of the eminent services which Mr. Thompson had so long and so effectively rendered in support of the important railway interests of the kingdom.'"

Sir Harry sat in Parliament for Whitby from 1859 to 1865. He stood for one of the divisions of the West Riding in 1868, but was defeated by a small majority; and in 1871 he declined, on the score of health, the offer of an uncontested seat for Whitby. He took an active share during the whole of his life in county business, and served as High Sheriff in 1856. The baronetcy was conferred upon him in 1874, only a few months before his death, which occurred in May; and none are likely to dispute that it was an honour well deserved and worthily bestowed. Sir Harry was elected an Associate of the Institution of Civil Engineers on the 10th of April, 1866.

Mr. JOHN ROE was born at Ashbourne, in Derbyshire, on the 24th of July, 1795. He was educated at Skipton, Uffington, and Wantage Academy. In 1813 he assisted his father in the construction of the Wilts and Berks Canal; also, about the years 1820–1826, in the construction of the Regent's Canal. As a contractor he carried out numerous works, both public and private; among them a railway from Moreton-in-the-Marsh to Stratford-upon-Avon in 1825, also a road near Long Compton in 1827.

In the year 1830 he was appointed surveyor to the Holborn and Finsbury Commissioners of Sewers, an office he held until the commission was superseded. He eventually became Surveyor-in-Chief to the Metropolitan Commissioners of Sewers, and finally retired from that office on a pension. During his term of office he carried out a series of important and valuable improvements in relation to drainage. After making a number of observations, and ascertaining by measurement the proportion of liquid to solid sewage, also the quantity of sewage matter carried off by the sewage stream in suspension, he established the present practice of cleansing sewers by flushing, and abolished the obnoxious system of opening the sewers and lifting the sewage by windlass and bucket. Then followed the construction of egg-shaped sewers in lieu of flat-bottomed sewers and semicircular-bottomed sewers, also of side entrances, improved gully drains, and house drains. Mr. Roe introduced the system of pipe drains, and expended much time for many years in ascertaining the effect of rainfall upon the sewage streams within the sewers. Night and day, for a long period, the sewage and rainfall of a given area were measured, the rainfall gauged, and the loss by absorption in different soils and by evaporation ascertained. The plan of emptying by the night-cart gave way to that of removal by pumping, after disinfection and dilution, direct into the sewers; and eventually the cesspools, to a large extent, were abolished, and the present prevailing system of water-closet established. A series of experiments were also carried out on the quantity and velocity of water flowing through pipes of different diameters and varying falls. The results of some of Mr. Roe's investigations were embodied in the tables published by the General Board of Health, in 1852 and subsequent years, in their Minutes of Information for Local Boards of Health.[1]

Mr. Roe also designed a scheme for the Northern drainage of London, and his Report thereon was presented to the Metropolitan

[1] *Vide* also Minutes of Proceedings Inst. C.E., vol. xii., p. 96.

Commissioners of Sewers on the 23rd of October, 1854.[1] In 1850 Mr. Roe was appointed to carry out the drainage of Windsor. His advice was also obtained for the drainage of Eton, Eton College, Derby, Beaconsfield, Reading, Harrow-on-the-Hill, and other places. In the drainage of Harrow the outfall pipe was 18 inches in diameter only.

Mr. Roe was elected an Associate of the Institution on the 1st of February, 1842, and on the 19th of the same month contributed a Paper "On the Causes of Accumulation of Deposit in Sewers,"[2] in which the usual mode of removing that deposit was alluded to, and a description was given of a flushing apparatus for cleansing sewers. He died on the 15th of March, 1874, aged seventy-nine years.

General Sir JOHN MARK FREDERIC SMITH,[3] K.H., R.E., F.R.S., the son of the late Major-General Sir J. F. Sigismund Smith, K.C.H., R.A., and grand-nephew of Field Marshal Baron Von Kalkreicht, Commander-in-Chief of the Prussian Army, was born at the Manor House, Paddington (then the only house there), on the 11th of January, 1790. He entered the Army as second lieutenant of the Royal Engineers, on the 11th of December, 1805; and, after passing through the various grades, finally became General on the 3rd of August, 1863, and was the senior Colonel Commandant of the corps of Royal Engineers. He thus held commissions from four sovereigns. He served in Sicily from 1807–12. In 1809 he was at the siege of Ischia and the capture of that island, and of Procida, in the Bay of Naples. He was also at the capture of Zante and Cephalonia. In 1810, in the action before the investment of the fortress of Santa Maura, he was deputy assistant-quartermaster-general, and at the siege and capture of the fortress he served as an officer of Royal Engineers. He was Inspector-General of Railways till November 1841; and in that capacity he examined and reported on the London and Birmingham, and the other principal railways before they were opened to the public; besides being on several occasions a Royal Commissioner on railways, harbours, &c. In 1845 he was Chairman of the Commission to Inquire into the Gauge of Railways, and, in 1846, one of the Commissioners appointed to investigate the various projects for establishing

[1] A copy of this Report is preserved in the Library of the Institution. [Tract, 8vo., vol. 108.]

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 132.

[3] The substance of this notice is taken from the "United Service Gazette."—Ed.

railway termini within or in the immediate vicinity of the metropolis. In 1841 he made a report, in conjunction with the late Professor Barlow, to the Lords of the Treasury, respecting railway communication between London, Edinburgh, and Glasgow. He was the commanding Engineer of the London district in 1830–1, during which period he made frequent reports for the information of his late Majesty William IV.; he commanded the Royal Engineers at Portsmouth in 1851, and afterwards at Chatham and Aldershot. He was M.P. for Chatham, in the Conservative interest, from 1852–3, and again from 1857–65; was the author of a translation of Marshal Marmont's work on the "Turkish Empire," with military and political notes; and was appointed, in March 1834, Gentleman Usher of the Privy Chamber, which office he held to the time of his death. He was widely known and greatly respected, having been in the Army just sixty-nine years, and connected with the Court for more than forty years.

Sir Frederic Smith was elected an Associate of the Institution of Civil Engineers on the 23rd of February, 1841. He died on the 20th of November, 1874, at his residence in Pembridge Villas, Notting Hill, and was buried at the Kensal Green Cemetery.

Mr. WILLIAM WOODCOCK was born in the year 1814, at Hinckley, Leicestershire, and was educated near his native town, where his father was a manufacturing hosier. Upon leaving school he assisted in the business until his father's death, after which he remained in partnership with his brother until the year 1848, when he came to London and turned his attention to brewing. During the time he was so occupied, owing to the "Smoke Nuisance" Act, his thoughts were directed to the question of the consumption of smoke, and to the best method of setting steam boilers. Subsequently he invented a method for effecting the former object in steam-boiler furnaces, and he devoted his whole energies for some years to matters connected therewith. Whilst so engaged he was introduced to Mr. (afterwards Sir Goldsworthy) Gurney, and, in conjunction with him, brought out the Gurney stove. Mr. Woodcock then became the Managing Director of the London Warming and Ventilating Company, a company which has proved in every way a success, and has supplied warming apparatus to the principal cathedrals in England, including St. Paul's. In the year 1870 Mr. Woodcock made arrangements to purchase the business of the company from the shareholders, which at the time of his death, at Brixton on the 15th

of August, 1874, he was still carrying on with the assistance of his eldest son.

Mr. Woodcock took out several patents connected with the subjects of warming and ventilation, including improvements in the original Gurney stove. He was elected an Associate of the Institution of Civil Engineers on the 9th of January, 1855. A Paper of his, entitled "On the Means of Avoiding Visible Smoke from Boiler Furnaces,"[1] was read before the Institution on the 14th of November, 1854. He also took a prominent part in a discussion on a subsequent Paper on Steam Boilers.

Mr. Woodcock was possessed of great energy and sound common sense. His integrity of character and unassuming manners, together with his thorough knowledge, both practical and theoretical, of the subjects to which he devoted a great part of his life, won for him the esteem and regard of all those with whom he had business relations. Of his private life, it is sufficient to say that it was a bright example for his children to follow, and that his memory will always be held in most affectionate regard by many friends.

Mr. CHARLES FAVELL FORTH WORDSWORTH, Q.C., was born at Harwich in 1803, and was the son of Mr. Robinson Wordsworth, a relative of the Poet-Laureate. He was educated at the Grammar School in his native place, was called to the bar in January 1833, and became Queen's Counsel in June 1857. He died on the 18th of February, 1874, after a short illness, from bronchitis. He was the author of the following works: "The Law of Joint-Stock Companies," which ran through several editions; "The Railways Construction Facilities Act, 1864;" "The Law of Railway, Water, Gas, and other Companies, requiring express authority of Parliament;" "The Law of Compensations, by Arbitration and by Jury, under the Lands Clauses Acts;" "A Summary of the Law of Patents for Inventions;" "Practice at Elections of Members of Parliament." And he contributed frequently to legal and other periodicals. In 1857 he unsuccessfully stood for Paisley in the advanced Liberal interest. He was elected an Associate of the Institute on the 21st of January, 1851, and was in 1852 appointed Honorary Counsel, which position he held until his decease.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 1.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On the Distribution of Loads over the Superstructure of Bridges.

By M. Lavoinne.

(Annales des Ponts et Chaussées, Feb. 1874, pp. 166–203.)

The superstructure of bridges usually consists of longitudinal beams, united by cross bearers, on which rests the actual roadway. The strain on a beam is generally calculated by supposing it to support the load which rests on the nearest half of each of the spaces between it and the adjacent beams. If, however, the cross bearers are continuous across the bridge, they will to some extent distribute this load over the whole of the beams, instead of leaving it concentrated on one. The object of this paper is to investigate the effect of this distribution, and to determine how far it should be allowed for, in designing the beams or main girders of bridges.

The general theory of what may be called "mat-work systems" (that is, composed of two sets of ribs crossing each other at right angles) has been given by the same author in the "Annales des Ponts et Chaussées" for 1867, the subject being a kindred one, viz., the strains upon the vertical planking and horizontal ribs of a lock gate. The problem as there stated is as follows:—Given a number of parallel ribs, supported at their extremities and crossed at right angles by other ribs which are loaded in a given manner, to find the bending moment of any rib of either system at any point of its length. The investigation of this problem leads to numerous and complicated equations. To simplify matters, it is assumed in the present memoir (1) that the cross bearers are close together, and infinitely narrow, so as to cover the whole surface of the bridge; (2) that the beams are either three or four in number; (3) that both the beams and the cross bearers are of constant section throughout; (4) that the load is one of two classes, viz., either distributed over the whole length, and covering a zone of constant width, or else isolated in the middle of the span, and occupying a certain width on each side of the centre line.

First, in the case of three beams of equal strength, the final results show that no material advantage is gained by the cross bearers being continuous across the bridge, except when the load is equally distributed on each side of the longitudinal axis. If

however, the load be evenly distributed over the whole surface, the strains on the three beams tend to become equal, as they would be if the beams were independent, and each carrying the same load. It follows that the effect of cross bearers in distributing loads is very great where these are permanent and uniform, but small where they are local and accidental.

In designing a bridge with three beams, it is usual to make the central one twice the strength of the others. On examining this case, it appears that, with a symmetrical load, no advantage is gained by the continuity of the cross bearers; and on further comparison, it is seen that, for a bridge of three beams, a central one of double strength, with discontinuous cross bearers, is the most economical design, in point of materials, which can be employed.

The case of four beams is next examined. The equations are more complicated, but their development leads to the same results as those just given, viz., (1) The continuity of cross bearers is useful only with a symmetrical load covering the whole bridge, and with an unequal load it is a positive disadvantage; (2) The most economical design is one in which the cross bearers are discontinuous, and the middle beams are double the strength of those outside. The problem of a larger number of beams than four is not discussed in detail; but an attempt is made to examine it by adopting the hypothesis that the cross bearers are rigid, or, in other words, infinitely strong, so that under all circumstances of strain their form is that of a straight line. The investigation appears to point to the same result, viz., that the continuity of cross bearers is not to be recommended.

This conclusion is the reverse of that arrived at in the former memoir with reference to lock gates, as it is there shown that the effect of continuous vertical planking is to convey a great part of the pressure to the sill, and to distribute the remainder nearly equally over the ribs of the gate. The difference between the two results is due to the fact, that in a bridge there is no solid support corresponding to the sill, and that the loads are more symmetrical.

W. R. B.

Graphic Method of calculating the Stresses on Roof-trusses.

By Otto Spiesz.

(Civilingenieur, xx., 4, 1874, cols. 206–216.)

Only those constructions are dealt with in this essay the members of which are subjected to simple tension and compression. Further, all the arrangements of bracing have at least one pair of members connected together, and reaching from one abutment to the other. Those constructions, the general outline of which is trapezoidal, or which are not bounded by members forming a triangle, but are composed of a series of triangles arranged in succession, will be discussed in a second essay under the

head of bridges. Deviating from the customary method, in which the supporting forces at the abutments are first ascertained, and the stresses on the members of the truss derived from these proceeding from the extremities inwards, each separate load is followed, and the supporting forces are obtained as a final result. The forces in the several members are exhibited in the diagrams, as sums, in which the part due to each separate load can be recognised with facility. Accordingly, this graphic method serves not only for the solution of special numerical examples, but also for discovering the fundamental law of the distribution of stress for each construction.

The Author investigates first the simplest roof-truss, consisting of two rafters, inclined upwards so as to be in compression, or downwards so as to be in tension. By combining the results he gets the diagram for a roof-truss, consisting of a pair of rafters, a bent tie, and a kingpost. He then replaces the kingpost by a triangle of bracing. Lastly, he shows how the diagrams for the more complicated forms of roof-trusses may be built up out of the simple diagrams previously obtained. The method could not be rendered intelligible without illustrations. W. C. U.

Graphical Determination of the Weights, corresponding to a given Span and given Unit Strain, which a double T *Iron can support, when resting on two Bearings, and of which the moment of Inertia and Depth are known.* By M. DE BLONAY.

(Mémoires de la Société des Ingénieurs Civils, May 1874, pp. 278–279.)

The relation between the moment of strain and the moment of resistance of a beam or girder, resting on two supports, with a span and load uniformly distributed corresponding to a given unit strain, is expressed by the general equation

$$\frac{P\,C}{2} = \frac{R\,I}{V_1},$$

In this equation C is equal to the half span, P half the total load uniformly distributed, and $\frac{R\,I}{V_1}$ the moment of resistance. If 2 C and 2 P, or the span and the load, be considered as variable quantities, and be represented by x and y respectively, then, putting A for the constant quantity $\frac{8\,R\,I}{V_1}$, the preceding equation may be written $x\,y = A$, the equation of a hyperbola with respect to its asymptotes.

Without altering the value of the ordinate, let the abscissa x be replaced by another x having the value of $\frac{1}{x}$, and it may

then be written $y = Ax_1$, the equation of a right line passing through the origin of the figure. When $x = 0$, $x_1 = \infty$. When the value of x increases, the corresponding value of x_1 decreases; and when $x = \infty$, $x_1 = 0$. Since the value of x_1 diminishes as the span increases, it is evident that the lengths of the spans should be regarded as starting in a positive direction from right to left. M. de Blonay observes that it is customary, and also more convenient, to start the abscissa from left to right, and therefore changes the sign of the angular coefficient in the last equation, thus putting $-A = B$, which gives $y = Bx_1$. This equation, which is that of a right line symmetrical with the former, represents the relation between the load and the span, with the difference that the positive values of the spans increase from left to right.

As there is no practical use in considering spans whose lengths are below a certain minimum, M. de Blonay takes the origin from the left at a distance a, the minimum span which is considered equal to $\frac{1}{a}$. The new abscissa X has for its value $x_1 + a$, and the equation becomes $y = B(X - a)$.

Whatever value may be given to B, the right line cuts the axis of x at the point where the abscissa is equal to a. It may, therefore, be completely determined by calculating the ordinate of a second point; for instance, of that which corresponds to $X = 0$. Afterwards the load can be graphically ascertained which corresponds to a span somewhat greater than $\frac{1}{a}$. The diagram prepared by M. de Blonay gives the loads not only for iron of the double T form, but for any description of beam of which the depth and the moment of inertia are known.

C. T.

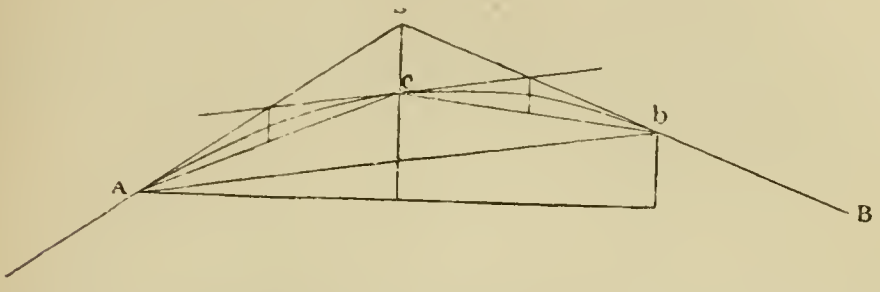
On the Joining of Inclined Lines by Parabolic Arcs.

(Annales des Conducteurs des P. et Ch., March to June 1874, 27 pp., 3 pl.)

Three methods of drawing a parabolic curve to join two inclined lines are compared. In the first method one point in each of these lines, being tangential points, and their point of intersection, are the data; a line is drawn between the tangential points, and the centre of that line being joined to the point of intersection already referred to gives a diameter of the parabola. The means of drawing the curve is described, but the method being complicated, it is not one to which the Author further refers. In the second and third methods a vertical line (see Figs. 1 and 2) is drawn from the point of intersection S, and a horizontal line from the tangential point A of one line of inclination of such a length that the vertical line bisects it, and a vertical line is let

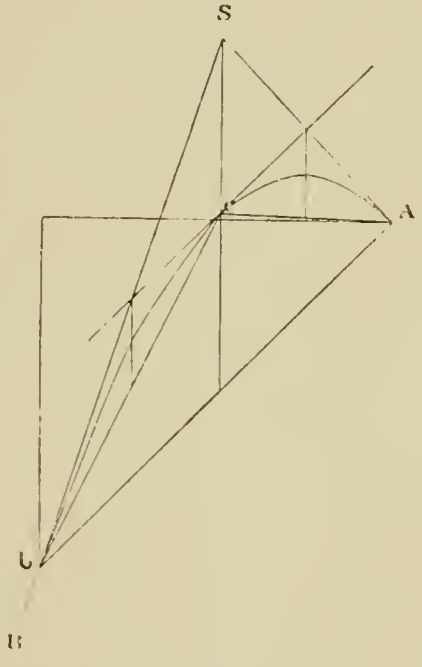
fall on or raised to the other line of inclination, the point of intersection (b) being a second tangential point through which the curve is drawn.

Fig. 1.



Join A b, and the centre of that portion of the vertical line from S above A b gives a third point c. If through c a straight line be drawn parallel to A b, it will cut the original inclined lines in two points; join A c, b c, drop verticals on these two lines from the two points, and their middle points will give two further points in the parabola. Other points may be obtained by a repetition of the same process.

Fig. 2.



The Author proceeds to explain that, the origin of co-ordinates being assumed at the vertex of the parabola, $y = \frac{x^2}{P}$ is the equation of the curve, where P represents the parameter. This equation is proved to take the form

$$y = \frac{x^2 p}{2 D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

where p represents the inclination per cent. on the incline, and D the distance from the point A along the horizontal line to the axis. The calculated value of D is then shown to be

$$D = \frac{2\,p\,L}{p+p'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

where L is the distance from the point A to the vertical line through S, and p' is the rate of inclination of the other line. The equation then takes the form

$$y = x^2 \frac{p+p'}{4\,L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

The following formulæ give the values of L, L′:—

$$L = \frac{d\,p' + H - H'}{p+p'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

$$L' = \frac{d\,p + H' - H}{p+p'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

where H and H′ are the depths of the assumed tangent points in the inclines below a horizontal datum line, whose length is d, in the first case H and in the second H′ being assumed as known.

The Author goes on to explain that, although the knowledge of the axis is necessary, it is not so *à priori*, and he gives the method of tracing the parabola from the assumed tangent point most distant vertically from the point of junction of the inclines, with the necessary formulæ.

The following cases may occur in practice:—

An ascent followed by a descent, or a descent by an ascent; an ascent followed by a horizontal, or a descent followed by a horizontal; an ascent followed by an ascent, or a descent by a descent; and an ascent or a descent of equal inclination.

From the examples of each of these, the following (Fig. 3) is selected, the calculation being made in feet:—

Data, $p = \cdot 05$, $p' = \cdot 04$, $H = 32 \cdot 8'$ $(10 \cdot ^{m})$, $H' = 26 \cdot 24'$ $(8 \cdot ^{m})$, $d = 164'$ (50^{m})

$$L = \frac{d\,p' + H - H'}{p+p'} = \frac{164 \times \cdot 04 + 32 \cdot 8 - 26 \cdot 24}{\cdot 05 + \cdot 04} = \frac{6 \cdot 56 + 6 \cdot 56}{\cdot 09}$$

$$= \frac{13 \cdot 12}{\cdot 09} = 145 \cdot 77' \ (44 \cdot 44^{m})$$

$$D = \frac{2\,L\,p}{p+p'} = \frac{2 \times 145 \cdot 77 \times \cdot 05}{\cdot 05 + \cdot 04} = \frac{14 \cdot 577}{\cdot 09} = 161 \cdot 977' \ (49 \cdot 38^{m}).$$

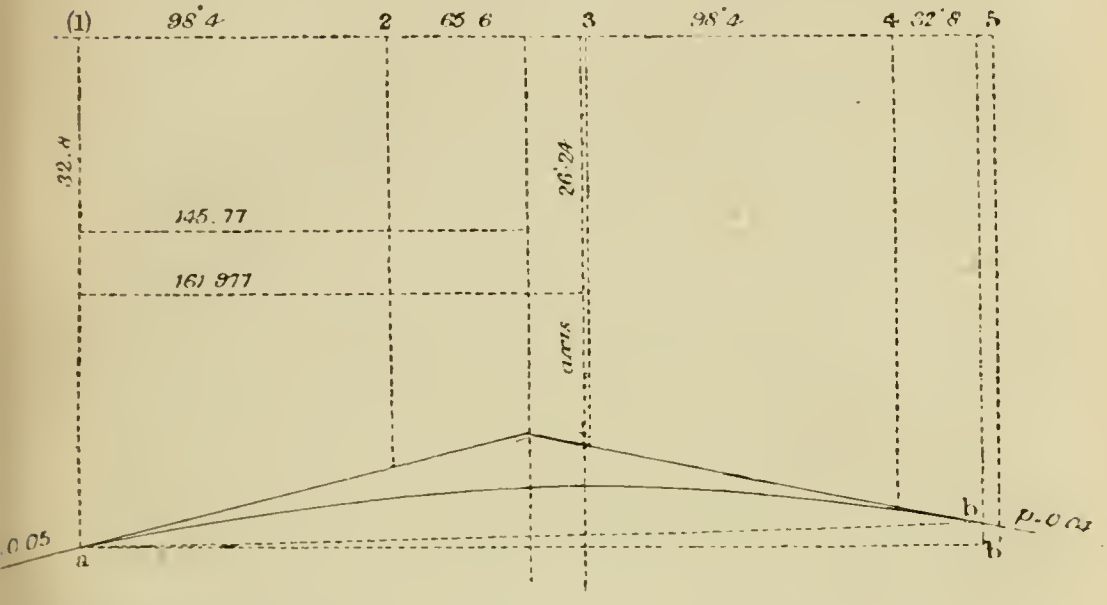
The following formulæ give points in the parabola, above the horizontal $a\,b'$ through the several points in the datum line.

Through 2—

$y = l\left\{p - l\left(\frac{p+p'}{4\,\mathrm{L}}\right)\right\}$, where $l = 98{\cdot}4'$ ($30{\cdot}^{\mathrm{m}}$), is the distance along the datum line from A to 2.

$$= 98{\cdot}4\left\{{\cdot}05 - 98{\cdot}4\left(\frac{{\cdot}05+{\cdot}04}{583{\cdot}08}\right)\right\} = 98{\cdot}4\,({\cdot}05 - {\cdot}015) = 3{\cdot}442'$$
$$(1{\cdot}05^{\mathrm{m}}).$$

Fig. 3.



Through the vertical—

$$y = \frac{\mathrm{L}}{4}(3\,p - p') = 36{\cdot}4425\,({\cdot}15 - {\cdot}04) = 4{\cdot}008675'\ (1{\cdot}22^{\mathrm{m}}).$$

Through the axis—

$$y = \mathrm{L}\left(\frac{p^2}{p+p'}\right) = 145{\cdot}77'\left(\frac{{\cdot}0025}{{\cdot}05+{\cdot}04}\right) = 4{\cdot}05'\ (1{\cdot}235^{\mathrm{m}}).$$

Through 3, where $l = 164'$ ($50{\cdot}^{\mathrm{m}}$) by the same formula as employed for point 2, *supra*—

$$y = 4{\cdot}05'\ (1{\cdot}235^{\mathrm{m}}).$$

Through 4, where $l = 262{\cdot}4'$ ($80{\cdot}^{\mathrm{m}}$) by the same formula—

$$y = {\cdot}25'\ ({\cdot}076^{\mathrm{m}}).$$

Through the second tangent point—

$$y = \mathrm{L}\,(p - p') = {\cdot}145{\cdot}77' \times {\cdot}01 = 1{\cdot}4577'\ ({\cdot}444^{\mathrm{m}}).$$

By subtracting each of these quantities from H, the depth of the

point A below the datum line, the points of the parabola are ascertained below the datum line.

The Author also gives a separate set of formulæ specially applicable to an ascent or a descent followed by a horizontal, and to an ascent followed by an ascent, and a descent by a descent.

E. F. B.

On small Oscillations of a Material System in Stable Equilibrium.

By F. Lucas.

(Comptes-rendus de l'Académie des Sciences, lxxviii., June 8, 1874, pp. 1635–1638.)

The case supposed is that of a body disturbed by a passing impulse, and left to oscillate freely about a position of stable equilibrium. It is pointed out that the whole energy stored up in the body at any given time (t) after the impulse is divided into

1. A translative energy (travail morphique) which has produced, and which is measured by, the distance of each particle of the body at the given moment from its position of equilibrium.
2. An impulsive energy which has produced, and which is measured by, the velocity each particle possesses at the given time.

Taking x, y, z to be the co-ordinates of any particle m referred to its position of equilibrium, and X, Y, Z the forces acting upon it parallel to the axes of the co-ordinates at the given moment, it is shown that—

$$\text{Translative energy} = -\tfrac{1}{2}\Sigma(\mathrm{X}x + \mathrm{Y}y + \mathrm{Z}z).$$

$$= -\tfrac{1}{2}\Sigma m\left(x\frac{d^2x}{dt^2} + y\frac{d^2y}{dt^2} + z\frac{d^2z}{dt^2}\right).$$

$$\text{Impulsive energy} = \text{half the vis viva.}$$

$$= \tfrac{1}{2}\Sigma m\left[\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2\right].$$

Taking one from the other—

$$(\text{Impulsive energy}) - (\text{Translative energy}) = \tfrac{1}{4}\Sigma m\frac{d^2v^2}{dt^2},$$

where v is the distance of any particle at the given time from its position of equilibrium.

Taking the mean values of the different terms in the above equation for a considerable interval of time comprised between the limits t_0 and t_1—

$$(\text{Mean of Translative energy}) - (\text{Mean of Impulsive energy})$$

$$= \frac{1}{2(t_1 - t_0)}\Sigma m\left[\left(v\frac{dv}{dt}\right)_1 - \left(v\frac{dv}{dt}\right)\right].$$

But as $v\frac{dv}{dt}$ is always small, the right-hand side of this equation tends to vanish as the interval $(t_1 - t_0)$ increases; hence the mean value of the impulsive energy = the mean value of translative energy; *i.e.*, the whole energy stored up in the body is made up on the average, half of impulsive and half of translative energy.

W. R. B.

On the Drainage of Clay Mountains. By Gustav Gerstel.

(Allgemeine Bauzeitung, Nos. 1 to 4, 1874, 32 cols., 4 pl.)

The Author, who had charge of the most difficult district of the Schässburg-Kronstadt line of the East Hungarian railway, finding that little had been written on the means of controlling the unseen and insidious power of water in veins, was compelled to investigate for himself the peculiarities of the forces and circumstances which caused landslips.

The district mentioned belongs to the Tertiary formation. In digging down from the surface the following series were met with: (1) the thin upper soil; (2) dry blackish yellow loam, about $6\frac{1}{2}$ feet (2 mètres) thick, which passes into (3) a clean yellow calcareous clay (Lehm), varying in thickness from 6 to 46 feet (2 to 14 mètres), and (4) a basis of stiff blue clay (Tegel), of small dip and undetermined depth. Sometimes between these there is a grey marly clay (Mergel), which falls to pieces on exposure to the air, and is so much cracked and split up as to be more or less permeable to water; this material occasionally replaces the yellow clay, and frequently contains much sand.

The steep, sharp spurs standing out from the principal chain towards the valleys, along which the railway winds, are of this grey marl, the ground in the secondary valleys between them being yellow clay. The latter is sometimes found in a plastic state, with here and there veins or cavities filled with water; in dry weather cracks open in the ground, through which water ultimately finds its way down to the surface of the blue clay, and by reducing the cohesion of the yellow clay itself and its friction on the underlying bed, gives rise to slips. To obviate this, it was necessary to search for water, and to drain it off as quickly as possible. Numerous borings were made, and trial shafts 50 to 100 yards apart were sunk for the purpose of ascertaining the depth of the impervious stratum of blue clay, which alone could serve for drainage, care being taken to note the manner in which water was met with and the quantity at each hole.

The drains were tunnels and trenches filled with stone. The drainage tunnels were 35 inches (0·9 mètre) broad at the top, and 43 inches (1·1 mètre) at the bottom, and from 3 feet 7 inches (1·1 mètre) to 4 feet 11 inches (1·5 mètre) in height. The trenches had a bottom breadth of 39 inches (1 mètre), with nearly vertical

sides; they were well timbered during construction, and in short lengths at one time. The fall given to the drains was never less than 1½ to 2 per cent. The bottom was about 12 inches (30 centimètres) below the surface of the blue clay, to allow for sediment. Where the trenches were merely required to carry off the underground water, loose stone to the depth of 39 inches (1 mètre) was laid at the bottom, then inverted sods, and the trench was filled up with earth. When they had to act also as surface drains, stone, or small round wood in the absence of stone, was filled in nearly up to the top.

Bank Slips.

It was impossible to avoid in some instances the use of yellow clay for banks; in such cases danger was reduced to a minimum by building up the banks in layers, and by giving them very flat slopes; and if bad weather set in, trenches were cut through the bank and filled in with stone, in order to allow the moisture to run off quickly. When the ground on which a bank was about to be made did not appear sufficiently dry and firm, it was first well drained by a system of longitudinal and transverse trenches and tunnels sunk into the blue clay; care being taken that all undulations of the surface of the blue clay were duly regarded, and that no depression was left out of consideration where water could accumulate.

If the side of a hill be itself slipping, it will be necessary to drain from 20 to 40 yards of the slope above the site of the proposed bank, to form a barrier to the slipping ground above; the bank must not be commenced till the ground has become thoroughly firm and dry. If, however, it be impossible to wait till this has taken place, a trench should be rapidly cut parallel to the bank, 5 to 10 yards from its foot on the valley side, with its bottom in the impervious stratum, and afterwards be filled up with stone in the manner described. The slope on that side of the bank will thus be drained, the friction of the mass on the impervious stratum increased, and the bank will receive a support which will prevent its slipping.

The following case shows the necessity of investigating the cause of slips before adopting any means to obviate them. At 23·7 kilomètres from Schässburg, a bank varying from 3 feet 3 inches to 6 feet 6 inches (1 to 2 mètres) in height was intended to carry the line along the side of a hill washed at the foot by a stream, which when swollen reached the bank. The ground, with half of the bank, began to slip, and in spite of a trench of the usual description cut parallel to the line up the side of the hill, continued to slip. Borings proved that, between the trench and the bank, the blue clay formed a watershed, and therefore the trench did not affect the drainage of the ground below. It was found necessary to clear away a great part of the bank with the slipping ground, and to dig a firm foundation for the former in the blue clay, along the deepest line of which stone

was filled in to carry off any moisture. After this the bank stood firm.

The following case of a length including a cutting and a bank deserves particular notice. Between the cutting, which was about 11½ feet (3·5 mètres) deep, and the stream, the ground was on the move, and in certain parts swampy. Borings showed that below the top clay, at a depth of 2 yards, the earth was replaced by a sandy marl, which was often so saturated with water as to be in a running state; at a depth of 26 feet (8 mètres) there was less sand, and the ground was drier: it was determined to take this stratum for the drainage level, as the blue clay could not be reached. Parallel to the cutting on both sides, some distance off, trenches were sunk, the bottoms of which were arched over with dry masonry, and the rest filled up with stone and wood. To obtain the greatest fall, and to get rid of the water in the most expeditious manner, these were drained by four trenches at right angles to the line. The ground soon became firm, and all slipping ceased.

The bank which succeeded this cutting carried the line over a depression in the hillside, down which, from a distance of 220 yards (200 mètres) above the bank, the ground was moving. Borings proved that the yellow clay, at a depth of 20 to 26 feet (6 to 8 mètres), was succeeded by saturated marl similar to that in the cutting, which attained here a depth of 46 to 49 feet (14 to 15 mètres). A trial shaft, sunk in the middle of the area to control the results of the borings, could not be proceeded with beyond a depth of 6 mètres, the pumps not being sufficiently powerful to keep under the stream of water which poured in. It was concluded that the cheapest way of getting rid of the water would be to erect pumps on the spot, which should be set to permanently drain the ground. While the matter was still under consideration, the overflow of one of the trial holes suggested the idea of getting rid of the water by the force of gravity, after the manner of the artesian well. Accordingly, suitable holes were sunk at various places, from which open ditches, 2 feet (60 centimètres) deep, led off the water to a common drain, which passed under the bank into the stream. The success of these measures was complete. As a precaution, however, against the possible effects of continued rain, the bank was widened to the extent of 6 feet 6 inches (2 mètres) on the hillside; so that, should a slip take place, the permanent way alone would have to be brought into line.

Slips in Cuttings.

The same principle obtains, that the ground should be thoroughly drained before the work is commenced. Slopes should be made as flat as possible in treacherous ground; but even a slope of 3 to 1 does not render drainage unnecessary. Judging from the new curve of equilibrium which a slope takes after a slip, namely, with the upper part depressed and the lower part bulged out, it

would seem advisable to assimilate the slopes of cuttings to this form. Thus, for a slope of $2\frac{1}{2}$ yards vertical height, the first $\frac{1}{2}$ yard from the bottom may have a batter of 2 to 1, the next vertical yard one of 5 to 1, and the rest a batter of $1\frac{1}{2}$ to 1.

Care must be taken in treacherous clays to finish off the slopes as the excavation proceeds from the top to the bottom. The opening up of gullies should be avoided; but if this method of working is adopted, the wall of the gully nearest the side of the cutting should be of the proper slope itself, and only the earth in the middle taken out in the usual manner.

Catch-water drains close to the top of the slope are objectionable, as the water in time eats its way to the slope. As soon as possible trees should be planted along the top for a width of at least 20 yards, to prevent cracking and yawning of the ground from drought.

When a cutting has to be commenced before the ground is thoroughly drained, retaining walls of dry masonry, with a batter of 1 to 1 and a breadth at the top of 3 to 5 feet, carried up from 3 to 13 feet (1 to 4 mètres) above the place on which sliding may be expected, will stop movement. But when this has already commenced, it is impossible to give any general rules for arresting it. Should there be no actual stream of water, but only an oozing, this action may be stopped by cutting trenches diagonally from the top to the bottom, from depths of from 5 to 8 feet, and filling them afterwards with stone.

If drainage beyond the immediate vicinity of the cutting be necessary, a proper system of trenches and tunnels can only be laid out after due consideration of the upper surface and of the impervious stratum of blue clay, the depth of which must be ascertained by numerous borings.

In the construction of the East Hungarian railway, the cuttings were easily and successfully carried out, but at the east end, the tunnel, which begins at 39·9 kilomètres from Schässburg, presented from first to last great difficulties. This being the first important work of the kind, there was no experience to serve as a guide. It was considered at the time impracticable to sink the trenches down to the depth to which they should have been carried, namely 29 feet 6 inches (9 mètres); the consequence was the drainage of the ground was imperfectly effected, and the earth in the cutting kept constantly slipping. A great deal of the difficulty was got over by diverting the centre line at the end of the cutting, and by prolonging the tunnel for a length of 36 feet (11 mètres) through the worst part of the ground. By these means the work was sufficiently advanced to enable the railway to be opened. After this the cutting continued to give trouble, but the Author then left the service of the East Hungarian Railway Company, and cannot mention what steps were taken to obviate the slipping.

The Author concludes by remarking that, where it was possible, expensive drainage works were avoided, and the material for the

banks was taken from side cuttings. These side cuttings were made with flat slopes, and themselves afforded a protection to the railway against slips, as they formed basins in which the earth moving from the hill could accumulate to a large extent before reaching the bank. H. D.

On Andernach Trass.

(Stoompost, Aug. 2nd and 9th, 1874.)

The tuffstone from which Andernach trass is ground is a volcanic product of the eastern Fifel range, on the left bank of the Rhine. The principal quarries are in or near the valley of the Brohl, and in the valley of the Nette, close to Andernach. The tuffstone consists of the ash ejected by the volcanoes in prehistoric times, compressed by thick layers of superincumbent pumicestone subsequently deposited, and it only crops out at or near the surface at the points above mentioned. In the Nettethal the superincumbent layer of pumicestone is more than 39 feet (12 mètres) thick. In the Krüfterthal it is only $3\frac{1}{4}$ to $6\frac{1}{2}$ feet (1 to 2 mètres) thick. The tuffstone, however, which is most easily obtained is that of the Brohlthal and its neighbouring valleys, where the layer is from $65\frac{1}{2}$ to 98 feet thick (20 to 30 mètres).

German trass is frequently and largely adulterated with wild-pumice, or other stone. In the Brohlthal the temptation to adulterate is great, for not only is the wild and bad tuffstone close at hand, but it must be removed before the good layers can be reached. Pumicestone is found also in large quantities in different parts of the Neuwied basin, and close to the tuffstone quarries.

Good trass may be known by the following characteristics:— When thrown in a heap, the slopes should run down readily. On being formed into a ball in the hand, unadulterated trass falls immediately into small pieces, and the pieces themselves separate; whilst with old, wild, or damp trass the ball falls at once to powder. Good dry trass should be strongly hydroscopic, a quality which is ascertained by exposing it for half a day on damp stones. The weight also of a given quantity of dry trass is greater than that of damp trass, owing to the volume of the latter increasing at a greater rate than the weight. Thrown into a glass of water and stirred, good trass sinks quickly, the water soon becomes clear, and only a few particles of pumicestone remain floating. The transition from the fine to the coarse particles in such a precipitate is much more regular in the case of good trass than in that of bad or wild trass. With wild trass especially, the coarser particles are covered with a yellowish, slimy coating resembling mud. When adulterated with sand, a considerable quantity of it forms the bottom layer of the precipitate.

The needle-test is that usually adopted, and is prescribed in

Holland for Government works. The diameter of the needle is ·047 inch (1·2 millimètre); and a mortar, consisting of two parts by measure of rich slaked shell or stone lime, and one part of trass, mixed with water to the consistence of putty, must, after three or four days, support such a needle when loaded with 10½ oz. (3 hectogrammes).

In applying the needle-test, it is essential to bear in mind that

1st. Mortar mixed with sea water will give a much less favourable result than that mixed with fresh water.

2nd. It is important always to mix the mortar to the same stiffness, otherwise there will be very discordant results.

3rd. Difference in the fineness of the trass, within reasonable limits, does not appear to affect its strength.

4th. The lime used for the tests should be slaked either by gentle sprinkling with water, or by absorption of water from the air. Shell lime is to be preferred to stone lime, being more regular and finer in its grain. It has not unfrequently happened with the latter description of lime, that the needle has rested on a coarser particle than usual, and thus given greatly exaggerated results.

5th. In loading the needle, care should be taken to increase the weight gradually and steadily.

A simple chemical examination will also aid in ascertaining the value of the trass, and in detecting adulteration. Ground trass has a composition of alumina, silica, lime, and oxide of iron, of which 50 to 60 per cent. is silica, and only about 5 to 10 per cent. lime. The silica, which is present in a soluble or gelatinous form, when mixed with lime and water forms a silicate of great hardness, capable of strong adhesive power, and of resisting the action of air and water. This characteristic of the gelatinous silica gives to the trass its setting properties, and the more of this silica there is in the trass the greater is its value.

Since lime is already present in the tuffstone, it is clear that in damp trass the conversion of the soluble silica will have partly taken place. Damp trass is therefore objectionable, and, as the trass itself is strongly hydroscopic, old trass is also capable, by the absorption of water from the air, of becoming set in its own constituents. This is one of the reasons why much of the tuffstone which comes from the Nettethal is of inferior quality. The quarries in that valley are much burdened with water, which renders the tuffstone damp.

Trass from tuffstone procured from old buildings is equally bad, even if the stones have not been set in mortar. If they have been so built, they will naturally have lost much more of their soluble silica by combination with the lime in the mortar, both during the building, and afterwards by the action of rain, &c. The chemical examination has for its object to ascertain

the presence and quantity of the gelatinous silica. The following is the simplest method :—

(*a.*) From 1·12 to 1·69 dram (2 to 3 grammes) of the trass to be examined must be boiled in 7 to 10½ oz. (2 or 3 hectogrammes) of concentrated hydrochloric acid. The yellow solution must then be diluted with water, upon which a turbidity of a greyish white colour will form, and only a few grains of sand remain undissolved. Being allowed to stand, the precipitate will settle until the solution becomes quite clear. After pouring off the liquid the precipitate must be boiled for a quarter of an hour in caustic potash, when it will be almost entirely dissolved.

This test is based on the following principle :—Silica occurs in trass in combination with alumina as a silicate of alumina, which with the rest of the constituents of the trass is soluble in concentrated hydrochloric acid. On the addition of water the silica separates from the alumina, as a flocculent gelatinous deposit of a greyish white colour. The alumina is only soluble in hydrochloric acid when, as in the trass, it is in combination with silica as silicate of alumina, or if, when free, it has not been heated to a red heat. This last, however, owing to its volcanic origin has taken place in the tuffstone ; it is insoluble in hydrochloric acid, but is soluble in caustic potash, as well as the silica, which becomes free on the dilution of the hydrochloric acid. If then

1st. The precipitate after the addition of water to the hydrochloric acid solution be not a greyish white, but brownish or blackish, it shows an adulteration with loam or clay, burnt clay, tiles, or slates.

2nd. If after treatment with caustic potash the precipitate is not entirely dissolved, it proves an adulteration with sand or wild trass.

(*b.*) To determine the quantity of gelatinous silica in good trass, comparative tests must be made with trass of a recognised quality, the basis being the solubility of the gelatinous silica in nitric acid. The more of this silica there is in trass the less will be the quantity of the precipitate. With measuring tubes the amount may be ascertained by a comparison of the precipitates of good trass, which will serve as a basis for a similar quantity of the trass to be examined.

In this test one characteristic of the precipitate, which will serve to detect adulteration, is that it must sink slowly. Stone dust, sand, or broken slate when mixed with the trass, from their greater specific gravity, sink first and lie at the bottom. The precipitate of wild trass also, containing little or no soluble silica, sinks before that of good trass ; and thus by comparing the colour and thickness of

the different layers of the precipitate with those of good trass as a basis, an indication of the extent of the adulteration may be obtained. A precipitate light-coloured on its surface proves adulteration with wood or peat ash, &c.

The strong effervescence of the trass, on treating it with hydrochloric or nitric acid, is however no proof of its adulteration with wild trass or with lime, since the tuff-stone itself contains a good deal of free lime. The effervescence must, it is true, be much less than when Portland cement is treated in the same way, since the latter contains about 54 per cent. of lime, and the Andernach trass only an average of 7 per cent. Trass ground from tuffstone procured from old buildings will show little effervescence, since the lime, as already stated, is for the most part combined with insoluble silica.

Adulteration with wild trass may also be detected by the microscope, which will clearly show small pieces of quartz enclosed in the wild stone, whilst in the genuine trass, the shining black colour of the obsidian, which is present in large quantities, may be recognised.

D. H.

Road-making in the Basses-Pyrenées. By M. Conte-Grandchamps.

(Annales des Ponts et Chaussées, May 1874, pp. 529–56. Figs. 1–16.)

Since 1836 parish roads (chemins vicinaux) have acquired great importance in France. The annual sum voted in 1870 for the maintenance of roads exceeded £5,500,000 sterling (138,000,000 francs), £1,840,000 of which were devoted to mail roads (chemins de grande communication), £1,080,000 to county roads (chemins d'intérêt commun), £2,240,000 to ordinary parish roads receiving subvention, and £360,000 to ordinary parish roads receiving none. From 1837 to 1871 the total expenditure was £120,000,000 sterling (3,000,000,000 francs); from 1871 to 1883, there will have been added £60,000,000 sterling (1,500,000,000 francs), when the round total will amount to £180,000,000 (4,500,000,000 francs). The Councils-General everywhere consider the development of roads of the utmost importance, and by the law of 1871 they have received the right of superintending county and parish roads. In many cases the existing state of things has been maintained; but in some the duties have been conferred upon surveying agents (agents voyers), and in others upon engineers. The question having arisen which did the work most economically, this Paper gives the results for the department of the Basses-Pyrenées, where the roads were during nine consecutive years, 1855 to 1864, in charge of surveying agents, and during a similar period, 1864 to 1873, in the hands of engineers.

From the official returns it is shown that the surveyors added a total of 64 miles (102,508 mètres) to the mail roads, the cost of

maintenance for each mètre being $2\frac{1}{2}d.$ (0·264 franc), and the cost of construction per mètre 10*s.* $5\frac{1}{2}d.$ (13·20 francs). The official accounts for county and parish roads are somewhat faulty between 1855 and 1861. The roads were in a very bad condition in 1861, and large sums had to be expended during 1861, 1862, 1863. The two accounts being mixed up, it is not possible to determine the exact sum belonging to each; but it appears that from 1837 to 1864 a total length of 741 miles (1,192 kilomètres) was constructed, the respective number of kilomètres for county and parish roads being 190 miles (306 kilomètres) and 551 miles (886 kilomètres). The expenditure during that period reached £384,240 (9,606,191 francs), from which, after subtracting 2,000,000 francs for maintenance, there remains a sum of £304,240 (7,606,000 francs) for 1,192 kilomètres constructed, the cost being 5*s.* $0\frac{3}{4}d.$ (6·38 francs) per mètre. The road-making consisted almost entirely of labour in discharge of taxes (journées de prestation), which is in most cases unskilled. The salaries of the officials, from 1855 to 1863, amounted to £18,104 (454,300 francs), or 6·93 per cent. of the entire capital.

When the engineers undertook the work, in 1864, the price of labour rose 10 per cent., from 1·60 franc to 1·77 franc per day. The last nine years included the disastrous period of the war; nor were the road-makers dismissed during the fine season, as had been done previously. To make a fair comparison therefore, one-tenth must be added to the sums quoted in the first period. During these years there were constructed 70 miles (113,199 mètres) of mail roads, and maintained a mean length of 488 miles (785,426 mètres), the cost of maintenance per mètre being $2\frac{1}{2}d.$ (0·23 franc), and of construction per mètre 6*s.* $7\frac{1}{4}d.$ (8·24 francs). The service of county roads was disorganised when the engineers undertook it in 1864. Some of the roads were under the surveillance of the Maire; others were maintained by subventions out of the county treasury; but there was no regular budget and no control. This had to be regulated, and the tax-labour defined. The engineers constructed during the second period 168 miles (269,892 mètres), and maintained a mean length of 274 miles (441,384 mètres), the cost of maintenance per mètre being $1\frac{1}{2}d.$ (0·141 franc), and of construction per mètre 4*s.* $1\frac{1}{4}d.$ (5·12 francs). The service of cross roads scarcely existed in 1864. The tax-labour (prestation) was often of an uncertain character, and it was not till the law of 1868 that sufficient time and funds could be devoted to these works. Under these circumstances the accounts up to 1869 are somewhat confused; but the following results are correct. The mean length maintained from 1864 to 1869 was 675 miles (1,086 kilomètres), and from 1869 to 1872, 918 miles (1,479 kilomètres), the cost of maintenance per mètre being about $1\frac{1}{4}d.$ (0·12 franc), and of construction 1*s.* 11*d.* (2·39 francs). This work, it must be remembered, includes the tax-labour which is unpaid. The salaries to officials during that period amounted to £20,226 (505,650 francs), or about $6\frac{1}{2}$ per cent.

In the first period therefore mail roads cost for maintenance 0·264 franc per mètre; in the second period 0·23 franc, a difference of 0·034 franc per annum, or 0·306 franc for nine years, in favour of the latter period. The new roads cost 13·20 francs per mètre up to 1864, and 8·24 francs from 1864 to 1867, the difference being 4·96 francs, or about 4*s.* per mètre. If the rise in the price of labour already referred to be added, the respective differences will be 0·54 franc and 6·28 francs. While the surveyors spent £6,012 (150,301 francs) per year to construct 7 miles (11,389 mètres) of mail road, and £6,950 (173,758 francs) to maintain 409 miles (659 kilomètres), the engineers, on the other hand, spent annually £4,988 (124,705 francs) to construct 8 miles (12,577 mètres), and £7,248 (181,197 francs) to maintain 487⅔ miles (785 kilomètres). During that period the engineers have with an extra expenditure of £298 (7,438 francs) maintained 78 miles (126 kilomètres) more of mail road than the surveyors, and in the same years have constructed 656 miles (1,055 kilomètres) of county and parish roads, or almost as much as the former authorities in the previous twenty-eight years.

It will be seen that the work of the engineers in the Basses-Pyrenées has been of great importance. Their resources consisted of tax-labour, and sums annually voted either by the communes or by the Councils-General. It was difficult to superintend the labourers, who generally had no experience of earthworks or masonry; the only thing they could do was excavating and stone-breaking, and to them, therefore, was assigned the maintenance of the existing county roads and the preparation of the new ones, while paid and skilled labour was reserved for the mail roads, the building of bridges, and general supervision. The entire work is mapped out throughout the department, and definite lengths of road are added to the net-work at fixed periods. Each season has its special work; printed instructions are sent round from time to time, and every one, from the chief engineer to the labourer, knows his alloted duty.

The wooden bridges of the old administration have been replaced by others of brick or of metal, erected with the utmost regard to economy; cut stone has almost disappeared, and in many cases the flags of Lourdes have been employed instead of timber. The old breadth, varying from 16 feet 4 inches to 19 feet 8 inches (5 to 6 mètres), has been maintained; but where an entirely new bridge had to be erected a single road of 9 feet 10 inches to 13 feet 1 inch (3 to 4 mètres) between the parapets has been considered sufficient. The metallic bridges are calculated to support a test load of 7 cwt. 3 qrs. (400 kilogrammes) per square mètre, and to bear a vehicle with a load of 5 tons 18 cwt. (6,000 kilogrammes) per axle. The strain on the ties does not exceed 13 lbs. (6 kilogrammes) per square millimètre. An accompanying table shows the nature and cost of many of the works executed since 1864.

J. D. L.

Striking the Centres of Arches—Slack-blocks and Sand-boxes.

(Annales des Conducteurs des Ponts et Ch., Jan. and Feb. 1874, 10 pp. 3 pl.)

It is impossible with the aid of ordinary slack-blocks to lower the centres gradually and uniformly at every point. The vibrations caused by the blows on the wedges are liable to be communicated to the arch, and the tenacity of the newly-made mortar joints is thereby endangered. Another defect is, that the total extent of the lowering of the ribs is limited to the thickness of the thinner edge of the wedge. The intensity of the vibrations in slackening the wedges will be very much diminished if the angle of inclination to the horizon be such that its tangent is nearly equal to the coefficient of friction of the material of the wedges. For the generality of hard wood the corresponding angle is about 33°. When the angle of slope is steeper than the angle of rest, the upper block is kept in position by a cord attached to a staple in each block. This cord is tightened by a wedge, the removal of which allows the upper block gradually to descend.

The vibrations are more effectually got rid of by adopting a set of three wedges. The two lower of the ordinary shape meet at their thin end, and the third, V shaped, rests upon them. The former, at first kept together by cleats, are gradually separated on the removal of the cleats by inserting a pinch bar between them. In a system similar to the above, except that the V-shaped wedge is undermost, the angle of slope is greater than the angle of rest. The upper blocks are kept together, either by a cord passing through a hole in each, or by a screw. When the screw is used there must be a slot in the lower wedge to allow it to descend. With the above methods great care is required to ensure an even settlement, since one set of blocks must not be slackened appreciably faster than the rest. To remedy this defect bags of sand were used. At first round props, with their feet dressed off to a point, were placed in front of the bags of sand, and on these being cut away the whole weight descended on the bags, which were emptied gradually through holes. This arrangement was defective, because, in reality, the instantaneous slackening—the most important feature—was effected at the instant the props were cut away. Another arrangement consisted of sand-bags and 'verrins,' a kind of vertical union screw-bolt placed in front. Since, however, the screw-bolt and sand-bag served the same purpose, the former method was discontinued.

Among the other contrivances for utilising the mobile property of sand, there is a pair of cast-iron cylinders of which the lower one has a bottom and no top; the upper one, of which the external diameter is equal to the internal diameter of the lower, has a bottom and a top with a small central hole in it. The lower one is nearly filled with sand, the upper one is inserted, and the two constitute one support. In the lower cylinder, of about 10 inches

diameter, small holes are pierced near the bottom, which are closed until the centres are to be lowered, when the sand gradually runs out and the upper cylinder descends.

The difficulty in this case is the loss of mobility of the sand caused by compression. This may be in part overcome by leaving a small opening between the lower and the upper cylinder, which is also initially filled with sand. The upper cylinder being pierced with holes as well as the lower, the sand escapes both upwards and downwards, and its mobility is thus increased. A third external cylinder is sometimes placed outside the lower one, which is pierced all over with holes, whilst the third external one is only pierced sufficiently to let out the sand at a slow rate. Between the second and third cylinders the sand cannot lose its mobility by compression, whilst the loss of mobility in the inner one is compensated for by the increased number of apertures. Where this third cylinder is not employed the discharge of the sand is facilitated by the use—1st, of external tubes about 2 inches diameter next to the cylinder and $\frac{3}{4}$ inch at the end; 2ndly, of internal tubes about 2 inches in diameter, and pierced all over with small holes of $\frac{1}{4}$ inch. This acts in the same way as the third cylinder above described. It is evident that instead of cast-iron cylinders strong wooden boxes may be used. The depth of the sand ought to be from 9 to 12 inches. Instead of sand a trial has been made with small lead-shot, but the flattening caused by the weight prevented the grains from running out freely.

W. D.

Upright Arched Bridges. By J. B. Eads, M. Inst. C.E.

(Transactions of the American Society of Civil Engineers, Oct. 1874, pp. 192–215.)

The Author advanced the proposition that, for railway purposes, an upright arched bridge could be constructed more cheaply than was possible with the suspension system. In the St. Louis bridge, the upper and lower members, which constitute a single rib of the span, consist of steel tubes 18 inches in external diameter, in straight lengths of 12 feet, the curvature, which is circular, but which differs by a few inches only from a parabola, being introduced at the joints. The two lines of tubes are placed at a distance of 12 feet apart from centre to centre, and are connected by a single system of triangular bracing. The mean temperature being taken at 60° Fahr., the effect of temperature, ranging from 20° to 140° Fahr., decreases or increases the length of the rib by about 6 inches. The extension causes the crown to rise, which relieves the lower tube of compression at the abutments; hence the upper tube at this part has to bear all the load, and its sectional area has to be increased accordingly. At the crown, owing to the upward bending, the lower tube has to do all the duty, and its sectional area has to be correspondingly increased. Contraction

causes the opposite effect; thus each tube has to be made of sufficient sectional area, both at the crown and at the springing, to bear the whole load on the rib. Without doubt, the most economical plan of supporting an equally-distributed load over a given span is by the catenary or suspended arch, and if the metal was equally able to sustain compressive and tensile stresses, the upright arch of the same curvature would be equally economical, no bracing being required in either to preserve the normal curvature. Hence, when unequally loaded, the only difference in the two systems consists in the amount of material required in the bracing. In the case of the upright arch, if one half of the span be loaded, a horizontal movement is given to the crown towards the unloaded side. To prevent this is one of the most important problems. The solution adopted by the Author consists of the introduction of an inverted arch under each half of the main arch, terminating at the abutments and crowns, and properly braced to the main arch.

With this arrangement, the main or upright arch is in compression throughout its length: under the loaded half-span the inverted arch is in tension; under the unloaded it is in compression. A horizontal tie or chord, of the length of the whole span, is also employed to resist the thrust of the main arch. In the case of a bridge of two or more spans, the method employed is to allow two adjacent extremities of the main arches to abut against one another, resting on a saddle movable on the top of the pier. Thus, when the arches are both equally loaded, the thrust of one balances that of the other. The only difficulty is in the expansion and contraction of the chords from variations of temperature. This may be met in the following way: to one end of a vertical lever movable about a horizontal axis in the saddle, the end of the chord of one arch is attached; to the other end that of the chord of the other arch. Thus, when the chords contract or expand, the lever simply turns about the axis. When, however, one span is loaded, the excess of thrust in its arch moving the saddle on the pier towards the unloaded span, causes a tensile stress in the chord of the loaded span, and, by means of the lever, an equal and opposite compressive stress in that of the unloaded span. The Author believes that the most economical system of bridge-building can be attained by these methods, and that a bridge of two spans of 400 feet for a double line of rails, with a versed sine of $\frac{1}{8}$ to carry a live load of 2·5 tons per lineal foot, can be constructed with the main arch of steel at a weight of 1·28 ton per lineal foot, or, with the main arch of wrought iron, 1·93 ton per lineal foot.

A. T. A.

Bridge over the Elbe at Aussig, Austrian North-Western Railway.

By W. Hellwag.

(Zeitschrift des Oest. Ing. u. Ar. Vereins, vi., 1874, pp. 114–117.)

This structure, which is 1,014 feet (309·23 mètres) in length, consists of a main bridge 750 feet (228·65 mètres) in length, and of a continuation on each side—on the right bank of one span, and on the left of three spans. The main bridge over the river has three openings of 233 feet 6 inches (71·225 mètres), 233 feet 4 inches (71·2 mètres), and 233 feet 6 inches (71·225 mètres) span respectively. The superstructure consists of continuous iron lattice girders 731 feet 3 inches (223 mètres) long, the bearings of which are 242 feet 9 inches (74 mètres) apart. The railway is carried on cross girders resting on the top of the main girders; while between the latter, at a lower level, is situated a tramway. On the outside of the upside girder there is a footpath 4 feet (1·25 mètre) broad, supported by iron brackets. The main girders are 24 feet (7·36 mètres) deep, and placed 18 feet apart (5·5 mètres) from centre to centre. The total weight of the ironwork of the central bridge is 996½ English tons (20,250 zoll centner), or 27·35 cwt. per foot (91·2 zoll centner per lineal mètre) run, of which 85·4 zoll centner belong to the main structure, and 5·8 zoll centner to the parapets, &c.

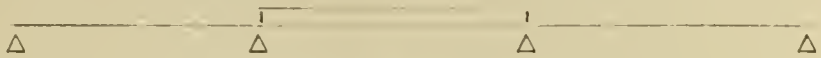
For testing the bridge the maximum load of 31·5 cwt. per foot (5,250 kilogrammes per lineal mètre) was applied. The corresponding deflection of the bridge under this load was calculated to be for the outer spans $1\frac{7}{32}$ inch (33·9 millimètres), for the central span $1\frac{3}{4}$ inch (44·5 millimètres), or allowing an excess of 10 per cent. $1\frac{1}{2}$ inch (37·5 millimètres), and $1\frac{15}{16}$ inch (49 millimètres) respectively.

In accordance with the orders of the Ministry of Commerce, the railway at the upper level was to be tested with a load of 24 cwt. per foot (4,000 kilogrammes per lineal mètre), and the tramway with 7·5 cwt. per foot (1,250 kilogrammes per mètre), together 31·5 cwt. per foot (5,250 kilogrammes per mètre). The corresponding load for one opening was produced by (*a*) five locomotives of 60 tons each, equal to a distributed load of 4,245 kilogrammes per mètre, and by (*b*) fifteen wagons heavily laden with stone, each weighing 5 tons, equal to a distributed load of 1,014 kilogrammes per mètre, making a total testing load of 5,259 kilogrammes per mètre.

The trial was divided into five phases, between each of which the bridge was relieved of all load. The first four phases consisted in loading—(1) the middle span, (2) middle and one side span, (3) two side spans, (4) middle and other side span, each span under test being weighted with the dead load of five locomotives and fifteen wagons as above. For the fifth phase three locomotives were run at high speed over the bridge, the lower roadway of the middle span being fully loaded.

Finally the lower roadway and footpath were tested for the maximum load of 6·8 cwt. per square yard (400 kilogrammes per

square mètre) by applying a dead weight made up of rails and stone. The bridge stood the test so well that permission to open it for traffic was given at once. The following are the deflections in millimètres at different points under the different phases :—

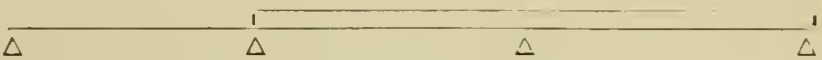


Girder down Stream side.

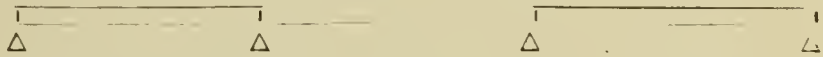
0·0	– 10·0 ($\frac{13}{32}$″)	0·0	39·0 (1 $\frac{17}{32}$″)	1·2 ($\frac{7}{64}$″)	– 8·5 ($\frac{11}{32}$″)	0·0

Girder up Stream side with Pathway.

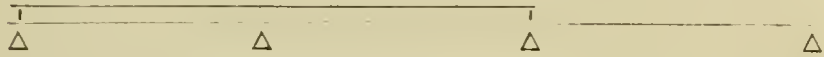
0·0	– 7·5 ($\frac{9}{32}$″)	2·0 ($\frac{5}{64}$″)	36·5 (1 $\frac{7}{16}$″)	0·0	– 8·5	0·0
Permanent deflection.			1·0			
			2·0			



0·0	– 9·5 ($\frac{3}{8}$″)	0·0	29·5 (1 $\frac{5}{32}$″)	1·2 ($\frac{7}{64}$)	29·5 (1 $\frac{5}{32}$″)	1·0
0·0	– 7·5 ($\frac{9}{32}$″)	0·0	28·5 (1 $\frac{3}{32}$″)	0·0	30·0 (1 $\frac{3}{16}$″)	1·0



1·0	39·0 (1 $\frac{17}{32}$″)	0·0	– 19·0 ($\frac{6}{8}$″)	1·2	39·5 (1 $\frac{35}{64}$)	1·0
1·0	40·0 (1 $\frac{18}{32}$″)	1·5	– 18·0 ($\frac{11}{16}$)	0·0	40·0 (1 $\frac{18}{32}$)	1·0



1·5	30·0 (1 $\frac{11}{64}$″)	1·0	29·0 (1 $\frac{9}{64}$)	1·2	– 7·0 ($\frac{3}{32}$″)	0·0
1·5	31·0 (1 $\frac{7}{32}$″)	2·0	33·0 (1 $\frac{9}{32}$)	0·0	– 6·0 ($\frac{1}{4}$″)	0·0

The sign – denotes a rising at that point.

During the five phases the maximum deflection of the middle span was 1 $\frac{1}{3}\frac{3}{2}$ inch (36 millimètres), of the side spans $\frac{2}{3}\frac{9}{2}$ inch (23 millimètres). At the end of the trial there was no permanent set, and the compression of the bearings on the piers also disappeared.

H. D.

Removal of Earth by Machinery from the Zizka Tunnel, Prague.

By Fr. Ržiha.

(Zeitschrift des Oest. Ing. u. Ar. Vereins, i., 1874, pp. 1–7, pl. 4.)

The situation of Prague, in the deep valley of the Moldau, renders the approach to the town by railway from the elevated plateau of Bohemia exceedingly difficult. The direction chosen for the Turnau-Kralup-Prague railway involved, after leaving Prague, a heavy cutting, and a tunnel through the Zizka Hill.

The deposition of earth from the cutting, estimated at 146,500

cubic yards (112,000 cubic mètres), was a matter of great discussion. The ground was too steep to admit of its being deposited on the town side of the tunnel, and in the suburb it was impossible. To carry it through the tunnel after a road had been laid, would have delayed the works, besides which the bank on the other side was destined to receive the earth from the station ground. No other place was found suitable except the top of the hill 112 feet (108 Austr. feet) above the formation level of the cutting. A rope tramway was laid up the hill, with a maximum gradient of 1 in 3, and with double lines for ascending and descending trucks. The engines were placed on the top, as the bottom was considered insecure, and space was wanting.

From the top of the incline the various tip and shunting sidings branched off, and from the bottom those for filling and arranging. With trains of four trucks, of 55 cwt. each, and a frictional resistance of 10 cwt., a tractive force of $74\frac{3}{4}$ cwt. was necessary, or for a speed of 5 feet per second, 87 HP. An old locomotive was bought and adapted for the purpose, by substituting for the driving wheels toothed wheels with gearing for turning the rope drums. The engine was lifted up to its place by jacks along a road laid for the purpose. The inclines were laid 6 feet apart from centre to centre, to a gauge of 27 inches, with rails destined for the permanent way; for the sidings lighter rails were used. The trucks for side-tipping were made on the Bystak system. On the bottom of the wagon ⊤ iron castings were fixed, the vertical flange of which rested in grooved castings or sockets bolted to the under frame; while running, the top was fastened down by a strap and key to the under frame. The latter was stiffened by diagonal bracing of flat iron. The couplings of the wagons were, for greater security, connected by a bar running through the frames.

The ropes, of stout wire, were $1\frac{1}{4}$ inch thick; two were required for working, during which they were well smeared, while a third rope was kept in reserve. The diameter of the rope drums was comparatively small, viz., 7 feet 6 inches, and they were broad enough to take up the entire rope. Along the centre of the roads, 20 feet apart, there were guiding rollers, and at the top of the incline grooved wheels to guide the rope before passing on to the drums.

The feed water for the boiler was supplied from a well at the foot of the incline, and was pumped up by a Decker's steam pump, through a $1\frac{1}{4}$-inch gas pipe, into a water-tight reservoir at the top. Steam was supplied to the pump from the locomotive boiler by a $1\frac{1}{2}$-inch pipe laid in a trench, surrounded by straw, a turn or loop being made in the pipe halfway to allow it to expand and contract. The pump delivered 2 to $2\frac{1}{3}$ cubic feet per minute to the height of 168 feet, and worked $1\frac{1}{2}$ hour per day during dinner-time. Telegraphic communication of the simplest kind was laid between the upper and the lower stations, which were not visible to each other. The roads at the top

and bottom were worked by horses. The line was ready for working in three months, and the first trains were run on the 1st June, 1871. At the end of the year the cutting was finished, but the engine was kept at work, drawing part of the earth excavated from the tunnel, till April 1872.

The whole time of working may be estimated at two hundred and ten full working days, omitting Sundays, holidays, and bad-weather days. In this time there were forwarded :—

Out of the cutting . . .	8,235	cubic Klafters.
Out of the tunnel . . .	1,675	„
Making a total of . . .	9,910	„

= 67,586 cubic mètres (88,402 cubic yards)

of earthwork measured in cutting, or an average of 421 cubic yards (322 cubic mètres) per day. During the chief part of the work, however, the quantity forwarded per day was 523 cubic yards (400 cubic mètres).

The expenses were :—

		£.	s.	d.
Preparing and laying roads, making trucks, purchasing and erecting machinery, pump, and telegraph, less price obtained by sale of locomotive, but without the cost of sleepers, rails of incline, and fastenings, which were borrowed .	fl.22,170 94	1,847	11	7
The working expenses of inclined road, including shunting of trucks, cost of coal, breaking-up and removal of road and machinery, but not including transport in cutting and on plateau .	fl.15,359 56	1,279	19	3
	fl.37,530 50	3,127	10	10

which is equal to fl. 3·79 per cubic kilomètre, or 8½*d.* per cubic yard (56 kr. per cubic mètre).

H. D.

St. Gothard Tunnel.

(Annales Industrielles, November 29 and December 6 and 27, 1874.)

During the month of August (1874), at the Göschenen end, between 1,125·8 and 1,245·8 mètres from the mouth, the heading passed through gneiss and talc-schist. The grey gneiss, met with at 1,099·4 mètres, continued for 176·8 mètres, containing 1·6 mètre of granitic gneiss rich in felspar. The mean bearing of the schist structure was 72° N.E., and the dip, 76° S., while the bands of talc-schist, which occurred in the gneiss, bore north-west and south-east, and dipped first to the north and then to the south. The talc-schist (1,176·2 to 1,199·4 mètres) was only distinguished from the veins of talc and mica by its great thickness. In some places the presence of quartz and of felspar crystals caused the talc-schist

to pass into glandulous gneiss with thin laminæ. The main bearing of the schist structure was 65° N.E., with a dip of 83° N., the numerous fissures forming an acute angle with the strike of the schist. The grey gneiss (1,099·4 mètres) differed from the previous structure by its resemblance to glandulous gneiss, and by the presence of a considerable quantity of grey mica in connection with brown glistening mica. Between 1,202·4 and 1,206·2 mètres, and also between 1,212·5 and 1,219·5 mètres, interruptions occurred of granitic gneiss, partly decomposed into geodiferous rock. The bedding of the gneiss generally bore 56° N.E., and dipped from 80° to 84° N., a bearing which was shared by the talc interruptions and the veins of felspathic granite. Besides these veins, others of talc and felspathic granite occurred, which bore more to the north, and dipped north-north-east, like the fissures. In one of the horizontal fissures (1,233 mètres) a pocket of rock crystal was found on the sole of the heading.

A few drops falling from the roof was all the water encountered. The mean temperature at the working face, 1,273 feet (388 metres) below the surface of the mountain, was 65°·7 Fahr. (18°·7 cent.), while that of the outer air at the mouth was 65°·5 Fahr. (18°·6 cent.). A progress of nearly 394 feet (120 mètres) was made during August, giving a mean daily advance of 12 feet 8¼ inches (3·9 mètres).

At the Airolo end, the heading passed through garnet-bearing mica-schist, between 988 and 1,014 mètres, containing some hornblende, silver-grey mica (a predominating feature), a considerable quantity of quartz, and brown garnets. It had a mean bearing of 55° N.E., with a dip of 69° N.W., and was but slightly fissured. Between 1,014 and 1,040·6 mètres, the heading passed through hornblendic mica-schist containing garnets, the predominating substance of which was grey quartz, with somewhat softer white quartz. Grey and white quartzite occurred between 1,019·5 and 1,021·5 mètres, and also between 1,022·5 and 1,026·5 mètres. The quartz and hornblende rendered the hornblendic mica-schist hard and tenacious. The mean bearing of the distorted strata was 52° N.E., with a dip of 58° N.W. The principal fissures formed an acute angle with the centre line of the tunnel; between 1,014 and 1,020 mètres their bearing was irregular and lined with serpentine and calcareous spar. At 1,040·6 mètres, the heading entered a schistose quartzite containing hornblende, rich in fine scales of silver-grey mica, but with scarcely any garnets. The thin, distinct, and regular beds bore 48° N.E., dipped 66° N.W., and were only slightly fissured. All the strata passed through during August crop out to the surface in the same order along the St. Gothard road, between the Chiasso quarries and the plateau of Tremola.

The above-named strata, though quite dry when first bored into, afterwards allowed a small quantity of water to ooze through. The mean temperature at the working face was 63°·5 Fahr. (17°·5 cent.), while that of the outer air at the mouth was

65° Fahr. (18°·3 cent.). The heading made a progress of 193½ feet (59 mètres) during August, showing a mean daily advance of 6 feet 4 inches (1·93 mètre). A large quantity of permanent-way material was delivered, and the buildings on the Lugano and Chiasso line made great progress.

During September the heading at the Göschenen end passed through gneiss containing interstratifications of talc-schist and felspathic granite, in the form of veins. The gneiss varied greatly in structure, and at 1,272, 1,296, and 1,338 mètres, was, for a short distance, decomposed into geodiferous rock. The two most important veins of talc-schist occurred between 1,259 and 1,264 mètres and between 1,340 and 1,345 mètres. The largest mass of felspathic granite was entered at 1,348 mètres; in it were found ordinary pyrites and epidote; more rarely, magnetic pyrites; and on one occasion (1,254 mètres) molybdenite. The mean bearing of the gneiss beds was 55° N.E., with a dip of 81° S.E.; and the bearing of the talc veins differed but slightly. The veins of felspathic granite either bore in the direction of the bedding of the rock, or in the prevailing direction of the fissures, N.N.W. Behind the thick vein of talc-schist, the parallel structure of the gneiss beds had an abnormal bearing, viz., from N. 50° to 62° E., and a dip of 45° to 79° N., thus corresponding with the bands of felspathic granite. The usual bearing of the fissures was from N. 6° to 36° W., dipping considerably, generally towards the west. Horizontal fissures appeared but rarely; and it was in the latter that the small pockets of rock crystal were met with. Some fissures, the bearing of which was 10° N.W., with a dip of 75° to 90° W., are remarkable as following the direction of the springs issuing from the clefts in the rocks of the large Upper Vallée du Diable. A small quantity of water, escaping from one of these fissures, flowed into the heading, and the geodiferous rock was almost invariably damp. The mean temperature at the working face, 1,033 feet (about 315 mètres) below the surface of the mountain, was 64°·5 Fahr. (18° cent.), while that of the outer air at the mouth was 58°·2 Fahr. (14°·6 cent.). The heading made a progress of 355 feet (108·2 mètres) this month, showing a mean daily advance of 11 feet 10 inches (3·607 mètres).

At the Airolo end, between 1,047·8 and 1,099 mètres, the heading passed through schistose quartzite, hornblendic mica-schist, and hornblende. The schistose quartzite formed, up to 1,052·7 mètres, the continuation of the rock previously described. The hornblendic mica-schist (1,052·7 to 1,077 mètres) contained garnets, and, on account of bands of softer quartz and of grey quartzite that closely succeeded each other, it assumed a streaky appearance, and was generally very hard. At 1,061 mètres, it passed into schistose quartzite, in which it continued for 4·5 mètres, the quartz having then become the prevailing element. The hornblendic mica-schist had, as a rule, a bearing of 51° N.E., with a dip of 69° N.W., and generally contained fissures lined with serpentine, chlorite, and calcareous spar, at an acute angle with the

slate structure. Some fissures, bearing north and south, were also met with, which contained water issuing from the wet strata more to the northward. Between 1,077 and 1,091·6 mètres, a hard and tenacious hornblende rock was encountered, principally composed of blackish-green hornblende, quartz, some felspar, black mica, and chlorite. Garnets were rarely met with; but small grains of ordinary pyrites and magnetic pyrites frequently occurred, as well as a considerable number of thin veins of crystalline limestone. The hornblende rock, instead of remaining uniform, alternated with thin layers of hornblendic mica-schist, and also with quartzite and mica-schist containing chlorite. The mean bearing of the strata was 46° E., and the dip 66° N.W. At 1,091·6 mètres, the hornblende rock was followed by a slight interstratification of quartzite. The infiltrations of water, which began again at 1,068 mètres, must have yielded, from this point to 1,099 mètres, as much as 1·1 gallon (5 litres) per second. The total flow of water in the tunnel, gauged at 1,092 mètres, was 51·48 gallons (234 litres) per second, and its temperature varied from 55°·8 to 56°·1 Fahr. (13°·2 to 13°·4 cent.). The mean temperature of the air at the working face was 62°·3 Fahr. (16°·8 cent.), while that of the outer air at the mouth was 59°·4 Fahr. (15°·2 cent.). Owing to the hardness and tenacity of the rock, the want of compressed air, and the inexperience of the men, the heading only made a progress of 168 feet (51·2 mètres), showing a mean daily advance of 5 feet 7 inches (1·707 mètre). The M'Kean, Ferroux, Dubois and François, and Sommeiller rock drills were used, an average number of eighteen machines being employed at once; and boring by hand proceeded in several places.

J. W. P.

On the Elasticity of Permanent Way. By M. Caillé.

(Memoires de la Société des Ingénieurs Civils, No. 1, 1874, pp. 133–167.)

The Author refers to a communication read before the Society upon the specimens of permanent way collected in the Paris Universal Exhibition in 1867. In 1864, the late M. Flachat pointed out the necessity of increasing the weight of rails, because their deflection, between the points of support, was appreciable even beneath the wheels of passenger-carriages and goods wagons. A short time afterwards he observed that deflection destroyed the rails, and prevented any increase in speed, because increase of speed was only possible by increasing the weight of the rolling stock.

In 1864 the main French lines had adopted rails weighing from 68 to 75 lbs. per yard, and, for the most part, the size and distribution of the sleepers still remain the same. If these types are

considered too light, and there is a tendency to increase their strength, the means hitherto adopted to preserve the integrity of the permanent way, and to prevent excessive deflection, are insufficient; but it does not follow that deflection of the rails within certain limits may not be permitted without injury to the traffic. In the forty years during which the cross-sleeper road has been tried, it has proved itself the only one capable of economically fulfilling all the conditions of stability and security.

Upon this basis, the Author examines the construction of various types of permanent way, especially that with cross sleepers, and inquires into the conditions regulating their maintenance. During the first twenty years of railway history, when traffic was insignificant, weights small, and speeds low, single or double-headed rails, carried in suitable chairs spiked to the sleepers, resting on the ballast, answered all purposes. As these primitive conditions altered, modifications and improvements in the form of the permanent way followed of necessity. But the nature of the ballast, its distribution over the formation, and the possibility of increasing or reducing its mobility, do not appear to have been the subject of special investigation. The importance of employing ballast has always been recognised, and different rails have been designed with the view of reducing its mobility, which, with all types of way, resulted in irregularity of bearing surfaces, highly destructive to the rails and rolling stock. To remedy this, packing was resorted to, with only temporary relief, the way remaining exposed to alterations in its normal levels. This led to an investigation directed especially to the weakness of rails, the excessive distance between the sleepers, the insecurity of the joints, and so forth. The flexure of the rails could be corrected in two ways; by increasing their weight, or by bringing the sleepers closer together. By preference the weights of the rails were increased—but insufficiently. As to the shocks sustained, by the ends of the rails under a passing load, the instability of the adjacent sleepers proved clearly, that it was necessary to prevent the flexure and sinking of these joints, and to unite the ends of the rails efficiently. Larger sleepers, placed more closely together, were introduced to meet the first difficulty; but in spite of all, the joints remain the weakest points of the permanent way. The temporary deflection of the rails under a passing load is not produced close to the load only, but at a distance on either side of its point of application, and the distance between the two points of deflection, and the point of contact of the load, increases with the rigidity of the rails.

It follows that regular deflection cannot exist unless the rails are uniformly rigid—a condition manifestly impossible. Thus, as the successive points of a rail sink before an advancing load, as the latter approaches the joint, the end of the adjacent rail is not able to continue the movement, and the joint forms, as it were, a fixed point, and consequently a projection, which is struck by the load and produces a permanent sinking. The Author, after stating that joint chairs and joint-chair sleepers have been abandoned, and

that fishes are used, discusses the principles involved in the several classes of fish joints, each represented by many forms.

Turning to the actual condition of permanent way upon French railways, he points out that, to obtain a uniform movement of the rails and sleepers, the ballast should be as homogeneous as possible. If sand be employed, it must be pure and of regular quality; if stone, it must be evenly broken. Sand opposes a comparatively feeble resistance to passing loads, but it yields without reaction, and reduces to a sensible degree the effect of the blows upon the superstructure of the way. If the ballast be of bad quality, its mobility may be increased by rain, reduced by dryness, and destroyed by frost.

The best ballast is clean gravel; but considering the requirements of packing, a mixture of gravel and fine sand is preferable. Broken stone must be often used, but it should be very hard, evenly broken, and not mixed with earth. Packing is required on account of the mobility of the ballast, to prevent the sleepers from taking a middle bearing; to effect which, a space of from 12 inches to 30 inches is left unpacked in the centre. The packing is therefore made on both sides of each rail, to an extent varying with the nature of the material employed. With broken stone, the extent ranges from 4 to 6 feet for each sleeper, with sand ballast it is generally 6 feet 6 inches long. The packing thus introduced may be regarded as a wedge, serving to restore the sleepers to their normal level. But the operation reduces the areas of support, and transfers the pressure to the lower bed of ballast, which is less mobile than that actually carrying the sleepers. These supports, therefore, should have an equal extent, and be equally distributed on each side of the rails; a condition rarely met with when the sleepers are good, and never when old and new cross-ties are mingled. It is necessary to give the superstructure a support, not only permeable, but uniform, to secure regularity in the vibrations of rails and sleepers.

Irregularity of movement in rails is due to imperfect fishing, to faults of construction, to defective laying, and to uneven wear, if they be of iron. Among the detailed causes of irregularity of the road are—the cutting into sleepers by chairs, or by the base of the rail, the flexure of the latter, and the gradual enlargement of the holes in the sleepers into which the pins or trenails are driven to secure the chair or rail. The cutting into the sleeper in straight lengths of way creates an inward inclination of the rails, which falsifies the gauge; while on curves, the reverse takes place.

Immobility in permanent way must result in its rapid destruction; but it may be useful to direct attention to the causes which led to the failure of certain modifications, seeking to impart greater rigidity, and thereby to reduce elasticity. Comparative rigidity can be obtained either by employing a cross-sleeper road, with rails of sufficient stiffness; by giving to the rails rigidity and bearing surface large enough, as in the Barlow system, to secure the immobility of the ballast; or by placing the rails on longitudinal

sleepers of such an area that the ballast shall remain undisturbed. The same result can be obtained in a cross-tie road, either by augmenting the stiffness of the rail by increasing the number of sleepers, so that the passing load is distributed over a sufficient number of the ties, or by laying the superstructure of either type upon rock, béton, or masonry. All permanent way should be considered as a compound structure, essentially required to accommodate itself to vibration and to the shocks of impact, which increase in intensity as the traffic increases in speed and weight. The best type is that which, giving full assurance of security, develops uniformly the greatest amount of elasticity. Practically, pure sand is incompressible when properly consolidated, and if the load be immovable. If the supporting surface is narrow, and the movement of the load puts the sand in motion, the sleeper will penetrate until it meets with sufficient resistance to check further displacement. Experience shows that the permanent way requires frequent local packing up, and occasional general lifting and restoration. Part of the ballast can, however, under certain conditions, resume its original state after the passing of the load. To estimate the weight transmitted to the ballast, it may be assumed that the length of packing for each sleeper is 79 inches. The bearing surface, therefore, will be about 10 inches $\times$ 79 inches = 790 square inches, neglecting the resistance of the ballast in the unpacked parts. If it be assumed that the ties all sink under the load, that the rails are rigid enough, and the sleepers so close together as to prevent deflection of the rails between them, it may be taken that the load affects at least four sleepers according to the stiffness of the rails, and thus the total supporting area will be about 3,160 square inches for a supposed load of 26,000 lbs. The total weight on the ballast would thus be 8·2 lbs. per square inch. But it is a rapidly moving load acting upon a free vibrating frame, the rigidity of which is sufficient to allow the rails to resume their normal place after the load has passed. The supports of the rails, including the packing, will thus penetrate the ballast, and this penetration will increase in depth and uniformity as the vibrations transmitted are more intense, as the ballast is better and of more regular quality, as the bearing surfaces of the framework are more equally distributed, and as the frame itself is less massive.

To sum up the foregoing :—Permanent way, the arrangement of which checks the vibration of its parts by too great or too little rigidity, or by the extent or ill-arrangement of its supports, develops immobility, hardness of ballast, and comparatively rapid destruction.

The double-headed rail, though it possesses the advantage that both tables may be used for traffic, is bad in form, and weak. Its inherent faults are not compensated by the advantage of reversing it, and this reversing indeed compromises the security of the road, destroys its elasticity, and favours abnormal deflection.

The Vignoles' rail, on the other hand, seems to combine se-

curity with durability. Resistance to rupture is ensured by the use of elastic iron of great tensile strength for the foot; and durability is obtained by employing hard iron for the head. But suitable iron is extremely difficult to procure, and the full advantage of the section can only be secured by employing steel. The Vignoles' rail, moreover, possesses greater transverse strength than the double-headed rail; it is also furnished in greater lengths, reducing the number of joints. In first cost, too, the advantage rests with the Vignoles' road in the proportion of from 5 to 7 per cent.

If a Vignoles' road be examined under a passing load, it will be noticed that its points of support have less motion than those beneath a double-headed rail. This arises from the more numerous cross sleepers, and especially from the interruption in the transmission of vibration to the sleepers and ballast, due to the weakness of the connections. The way can preserve its regularity longer, but its rigidity is apparent when exposed to impact. This regularity itself is only relative, changing constantly under the sinking and wear of the road. The stiffness and, to a certain extent, the transverse rigidity of the Vignoles' rail, and the method of securing it to the sleepers, aggravate the effects of the deviations, arising either from the wear of the rails, or from the state of the sleepers and ballast.

On account of the weakness of the joints, the Vignoles' rail requires careful examination, especially on curves. Experiments in France and in Germany demonstrate that these rails undergo temporary displacement during the passage of trains, and in this respect the Vignoles' rail possesses less security than the double-headed rail. Both have a tendency to assume an inclined position under the influence of the load, either inwards or outwards. In the Vignoles' rail this tendency can only be counteracted by employing saddles or by increasing the width of the foot, an increase upon which narrow limits are set; with the double-headed rail, on the other hand, the requisite support can be obtained by chairs.

The Author then discusses the relative advantage and disadvantage of the two systems of rails, and concludes that the difficulty of choosing between them arises from the fact that the Vignoles' rail maintains greater regularity than the double-headed rail, and thus partly compensates for its want of elasticity, while the latter loses by its mobility, and consequent irregularity, part of the advantage due to elasticity. The faults of the double-headed rail may be partially obviated by the use of good ballast, and by increased support, whilst the disadvantages of the Vignoles' section arising chiefly from the weakness of its fastenings, can only be remedied by changes that would introduce considerable modifications.

The deductions drawn by the Author are the following :—

1. That it is impossible to obtain absolute regularity by any system of permanent way.

2. That stability cannot be secured by immobility without sacrificing durability.

3. That permanent way can only be economical, when it is composed of durable materials possessing and retaining the necessary conditions of elasticity.

4. That, from this last point of view, the mobility of the ballast, however uniform and homogeneous, only supplies an irregular and insufficient means for developing the required elasticity.

5. That, moreover, the elasticity of permanent way does not exist at the joints, and can only be preserved throughout by the impracticable condition of maintaining the solidity of all the fastenings.

6. That the problem can only be solved by the adoption of a permanent way entirely of iron or of steel, which shall be elastic, yet possessing sufficient resistance, the flexibility of which shall be uniform at the joints and at the centre of the rail; where the stability—in a certain sense absolute—harmonises with mobility, and the elasticity of which, independent of any assistance from the ballast, secures the preservation of the whole system.

APPENDIX.

In the following Appendix, the then existing and proposed systems of permanent way upon the Eastern, the Northern, the Orleans, and the Southern railways of France are described:—

The Eastern Railway.

[The double-headed rail, weighing 75·5 lbs. per yard, is abandoned.]

An old type of iron rail, Vignoles' section, 71 lbs. per yard, height 4·724 inches, width of foot 3·937 inches. The rails are in lengths of 19 feet 8 inches, are fished, and each length is on six or seven sleepers, including the joint sleeper. The joints are supported by two sleepers adjacent to the joint sleeper, placed 29 inches on each side of the latter. Bed plates are employed at the joints inclosing the foot of the rail, received into the sleeper, and are provided with four holes for the fastening bolts. Longitudinal movement of the rails is prevented by their being notched on both sides at each end $\frac{1}{16}$ inch, and for a length equal to the bed plate.

Type 1. Steel rails, Vignoles' section, 75·3 lbs. per yard, in lengths of 19 feet 8 inches, laid as above.

Type 2. Steel rails, Vignoles' section, 60 lbs. per yard, height 4·724 inches, width of foot 3·897 inches, length 19 feet 8 inches, united by a suspended fish joint, carried on seven sleepers. The foot is neither notched nor pierced. Longitudinal movement is checked by a small iron bracket fastened to a sleeper by two wood screws, and butting against the fish-plate. The sleepers are of beech or pine creosoted. This section is specially designed to replace the two preceding, and for heavy traffic.

Lyons Railway.

[Abandonment of double-headed rail, weighing 77 lbs. per yard, laid down in 1849.]

Old type of iron rail, Vignoles' section, 70·5 lbs. per yard (1857), height 5·11 inches, width 3·93 inches, web $\frac{5}{8}$ inch thick, length 19 feet 8 inches,

fished and carried on six sleepers, including joint sleeper. There is a bed plate at each sleeper. The sleepers at the joint are placed 31 inches apart. Longitudinal movement is checked by a bracket fixed on both sides of the rail in the notches of the foot.

Type 1. Steel (1867), Vignoles' section, 78 lbs. per yard, height 5·11 inches, width 5·11 inches, length 19 feet 8 inches, with suspended fish joint, fished and carried on eight sleepers. On each side of the joints four sleepers are placed 11·8 inches and 27·5 inches apart.

Type 2. Steel (1873). In this type the thickness of the web is 0·55 inch instead of 0·629 inch, as in the preceding section, so that the weight is reduced by 2·2 lbs. per yard.

Type 3. Steel (1871), weight 70·3 lbs. per yard, height 5·039 inches, width 3·93 inches, web 0·55 inch thick, length 19 feet 8 inches, with suspended fish joint, carried on seven sleepers. Longitudinal movement is checked by a steel cylindrical pin fixed in a hole in the foot of the rail, and let into one of the sleepers.

Northern Railway.

[Abandonment of double-headed rail, weighing 74 lbs. per yard, laid down in 1846.]

Old type of iron rail, Vignoles' section, 74·3 lbs. per yard (1856), height 4·921 inches, width of foot 4·133 inches, width of head 2·44 inches, web 0·629 inch thick, length 19 feet 8 inches, fished and carried on seven sleepers. Longitudinal movement is prevented by iron keys placed in notches at the end of each rail. Sleepers of beech and elm prepared by the Boucherie process.

Type 1. Steel weighing 77·3 lbs. per yard. Similar to the preceding.

Type 2. Steel (1870), Vignoles' section, weight 61 lbs. per yard, height 4·921 inches, width of foot 3·81 inches, width of head 2·2 inches, thickness of the web 0·472 inch, fished over joint sleepers, length 26 feet 2 inches. Similar to the iron rail as above; fastenings also the same. This rail is carried on nine sleepers.

The joints of the two rails are not placed opposite. This appears to be a bad system.

The Orleans Railway.

[Two types of Vignoles' and double-headed rails are employed.]

Vignoles' rails are employed on those parts of the line which have the most frequent change of gradients.

An old section of double-headed rail (1849), weighing 72 lbs. per yard, height 5·198 inches, length 18 feet, first carried on five, afterwards provided with suspended fish joints, and then carried on six sleepers. Similar type in steel (1864). Size of chairs subsequently increased.

An old type of Vignoles' rail of iron (1861), 71 lbs. per yard. Same form as the old type of the Lyons railway.

Same type in steel 75 lbs. per yard.

The Western Railway.

[Double-headed rails exclusively used.]

An old section in iron, 75 lbs. per yard, height 5·118 inches, length 16 feet 4 inches, carried on five and six cross sleepers, including the joint sleeper. Chairs with large base, and fish-joint chairs employed. Longitudinal movement is checked by bolts placed in notches or holes of the joint chairs.

Same type in steel (1870), weight 77·8 lbs. per yard, height 5·118 inches, length 19 feet 8 inches, suspended fish joint, and carried by eight sleepers. Movement prevented by a stud in one of the fish joints extending into the chair.

SOUTHERN RAILWAY.

[Double-headed rail only employed.]

An old type of iron rail 74 lbs. per yard (1857), height 5·27 inches, width of head 2·48 inches, length 18 feet, suspended fish joint, carried on six sleepers; weight of chairs 22 lbs.

Similar type in steel 78 lbs. per yard, laid in the same way.

J. D.

Experiences in the working of Mountain Railways.

BY M. STEINSBERG, Manager of the Poti-Tiflis Railway.

(Organ für die Fortschritte des Eisenbahnwesens, No. 2, 1874, pp. 61–67.)

The construction of engines for steep gradients seems to exclude their adaptability for sharp curves. On the Poti-Tiflis railway the ordinary minimum traffic requires an adhesion upon the rails corresponding to a weight of 90 tons, or taking 15 tons per axle, six axles are required to sustain the adhesive weight. On the other hand, the sharp curves necessitate a wheel base not exceeding 8 feet for curves of $13\frac{1}{4}$-chains radius, and of 7 feet 6 inches for those having a radius of 8 chains. Engines able to perform such work, at a mean speed of $12\frac{1}{2}$ miles an hour, should be of about 600 HP., and have a heating surface of more than 2,150 square feet; this would involve such a length of boiler as to render it difficult to procure steadiness upon a short wheel base.

The great weight required increases the injurious lateral effect of the wheels against the rails, upon curves of small radius, and causes a waste of labour in overcoming the grinding of the outer wheels upon the rails. Another difficulty with engines for steep gradients is to keep the tubes and the top of the fire-box covered with water, this restricts the heating surface necessary for the production of sufficient steam, as in a boiler 22 feet long, on a gradient of 1 in 22, there is a difference of 1 foot in the level of the water surface at the two ends.

In engines for sharp curves, in consequence of the small wheel base and the unfavourable position of the boiler, an uneasy rolling motion is unavoidable, and the small diameter of the wheels, necessitated by the short wheel base, greatly increases the resistance to motion of the machine.

If this resistance is expressed by the formula

$$W = (p + p_1) f + p f_1 \frac{d}{D},$$

where

p = the weight of the engine without the wheels;
p_1 = the weight of the wheels;
d = the diameter of the axle bearings;
D = the diameter of the wheels;
f = the coefficient of rolling friction = 0·001;
f_1 = the coefficient of turning friction = 0·018 when good lubricating material is used;

it appears that the resistance to motion increases not only with the weight of the engine, but also with the reduction of the size of the wheels. These difficulties seem, at first sight, to be overcome by the 'Fairlie' engine.

Theoretically, the entire weight of the locomotive serves for obtaining adhesion, and from its position on two movable frames (bogies), it admits of the short wheel base necessary for passing round sharp curves. By the favourable position of the fire-box at the centre of the boiler, the relation of water level with reference to its top and the tubes is reduced to one-half the difference of level which would exist if the fire-box were placed at the end of the boiler. But these engines appear in another light when they have been observed at work; unavoidable defects become apparent, which are not mere faults in construction, but inherent to the system.

The most notable defect is the susceptibility of the steam-pipes to injury. A one-sided raising of the bogie frame, or the small shocks given to it by every alteration in the speed or difference in the level of the rails, affect the pipes at their point of connection. This results from the boilers being attached so loosely to the under frames, that every shock to the latter is injuriously felt by them before being transferred to the upper and greater mass of the machine. This defect became apparent on the Poti-Tiflis railway, where, in consequence of the weakness of the carriage couplings, the trains had at first to be pushed, instead of hauled, up the inclines. The frequent small back shocks to the forward wheel frame of the engine, in consequence of the variations of level or speed, occasioned perpetual injuries to the steam-pipes, so that the system of pushing had to be discontinued, and the number of carriages per train reduced, to enable them to be pulled up with safety. In the engines for the Poti-Tiflis line, the manufacturers had endeavoured to remove this defect by constructing the smoke-boxes of very thin plates, but they had afterwards to be stiffened.

Another important evil of the system is that the play or movement of the Fairlie engine is exclusively in a horizontal direction; that is, in a plane parallel to the rails, no play or movement taking place vertically. Mr. Ramsbottom tried the engines on a rising gradient, succeeded by a falling gradient beyond; so that on passing the summit the weight was shifted from the forward to the trailing wheels. When this occurs, slipping of the wheels on the rails follows as a natural consequence. This is not only injurious, but dangerous, as tending to throw the engine off the line; for it has long been a recognised fact that the rails do not possess sufficient lateral resistance against a rolling body, unless kept in position by a superimposed weight. The experience derived from the working of the Poti-Tiflis railway gave similar results. Careful drivers observed that during the passage over the mountains in the early morning, when the rails were damp and greasy, the wheels of the leading bogie frequently slipped on

iron bridges or viaducts; whereas with the same state of the rails on the ordinary road there was sufficient adhesion to prevent slipping. The Author believes the explanation to be, that there is generally a difference in the level of the rails on iron bridges and on the adjoining embankments. Upon steep lines, therefore, the shifting of a portion of the load from one set of wheels lessens the necessary adhesion on the rails and throws extra weight upon the other axles, to the detriment of the Fairlie engine, especially as, calculating on its easy running, the axles are one-sixth weaker than in ordinary engines of the same weight.

The tendency of these engines when thrown off the rails is to diverge, more than locomotives with fixed leading wheels, from the direction of the axis of the line, on account of the movable character of the bogie. This defect becomes more perceptible owing to the super-elevation of the outer rail on curves, which alters the position of the bogie frame, and prevents it from giving the long boiler a proper support; while by partially removing the weight from one rail and increasing it upon the other, the joints of the rails are exposed to dangerous strains.

The question of greater cost of repairs is as yet insufficiently known, but it is creating alarm. From the peculiar connection of the boiler with the wheel frames upon which it rests, shocks to the buffers do not distribute themselves equally over the whole machine as in the case of other engines, but are borne principally by the bogie frames. An accident on the Poti-Tiflis railway exhibited this fact clearly; in a collision at high speed between a small tender engine and one of Fairlie's, the latter was greatly injured, while the former was able to resume work.

These double locomotives are the more expensive, as one engine is rendered useless while the other is undergoing repairs. Moreover, for every four in stock only two and a half can be kept in working order, or only two where the traffic is heavy, whereas with ordinary engines the proportion is six out of eight.

These defects are conclusive evidence that the Fairlie engine ought to be restricted to mountain and mineral lines of secondary importance, and of narrow gauge. Under no circumstances is it suitable for the regular working of a mountain railway, where safety and regularity of traffic are indispensable.

The Author then describes an engine which he elaborated in combination with Herr Schau, Technical Manager of the Sigl works, Vienna. The eight-wheeled coupled engine has a wheel base of 10 feet 8 inches (3·25 mètres), or (omitting the leading and trailing axles, each of which is free to move laterally) a rigid wheel base of 3 feet 6 inches (1·075 mètre), the diameter of the wheels being 3 feet 3 inches (1 mètre). With an effective steam pressure of 9 atmospheres this engine developed a tractive power of 8 tons, which is equal to the adhesion of the engine for a coefficient of friction of $\frac{1}{9}$. This engine met the requirements of the Poti-Tiflis railway, but in order to reduce the dead weight still further, a 45-ton six-wheeled coupled engine is suggested as

sufficient for ordinary weather, the assistance of a second engine being employed when the state of the rails requires it.

The Author adds some calculations as to the maximum gradient and minimum curve admissible on mountain railways, and also as to the number of carriages which should constitute a train in various cases.

R. C.

Description of some Narrow-Gauge Railways.

By M. Ch. Ledoux.

(Annales des Mines, Nos. 2 & 3, 1874, 153 pp. 6 pl.)

M. Ledoux investigated the details and specialities of narrow-gauge railways in various countries, and has selected the following examples:—Line of Ergastiria in Greece, of Mokta-el-Hadid in Algeria, of Rochebelle, and of Cessous and Trébiau in the Gard. The eighteen smelting furnaces at the extremity of Ergastiria, on the eastern side of Laurium, a province of Attica, and about 7 miles from Cape Sunium, were established in 1864 for the treatment of 'ekbolades,' the slag of the ancients. To reduce the cost of transport M. Ledoux was entrusted with the construction of a narrow-gauge railway.

The route was marked by the road, uniting Berzeko with the coast, which crosses the central chain of hills by the pass of Rotonde, 560·8 feet above datum. The starting point is 11·8 feet, and the terminal point 286·3 above datum. A maximum gradient of 1 in 28 was adopted between the works and the summit, for empty wagons only, and of 1 in 38 between the summit and Berzeko, for loaded wagons. The gauge chosen was that of Mokta-el-Hadid, 1 mètre between the inside edges of the rails. The first section had curves of a minimum radius of 197 feet, and the second of 230 feet.

The principal dimensions of the rail are—height, 3·54 inches; width of top flange, 1·89 inch; thickness of web, 0·47 inch: width of bottom flange, 2·95 inches. The profile of the rail is adapted to fit the fish-plate. The inclination to the vertical of the line of contact is 125° 42′. It is moderately deep, the ratio of the depth to the half-width of the bottom plate being 2·4. For similar rails in actual use the value of this ratio is—Lyons, 2 and 2·6; Northern of France, 2·38; Eastern, 2·42; Cologne-Minden, 2·71. The fear, that in consequence of the sharp curves there would be a tendency to tilt the rail over on the outside edge of the bottom flange, has not been justified by experience. The exterior rails maintain their position, which proves that the width of the bottom flange is sufficient. The outward tendency has also been obviated by giving a great super-elevation, and a

considerable inclination of the rails towards the centre of the road. The rails are of Bessemer steel, and they weigh 41 lbs. per lineal yard. They were manufactured at Bességes, and their cost was £9 3*s.* per ton, delivered in trucks at that station.

The following is a résumé of the total cost of the work:—

	£.
Excavation, including labour, powder, and plant, &c.	3,954
Tunnel, including labour, powder, and plant, &c.	3,136
Works of art	1,584
Ballasting, labour and materials	903
Permanent way, do.	7,838
Level crossings, cottages, and fencing	134
Fixed materials, crossings, reservoirs, weighing machines	807
Engineering and staff expenses	1,624
Total	19,980

The total length, inclusive of the sidings at Ergastiria, is 6 miles 2 furlongs 1 chain. The cost per mile of the main line was £3,354 (52,121 francs per kilomètre), as against £2,711 (42,135 francs per kilomètre), the amount per mile such a line would have cost in France.

The tank engines, made at the works of Messrs. André Kœchlin & Co., at Mulhouse, at a cost of £1,250 each, were designed specially to suit the peculiarities of the line by M. Beugniot, the chief engineer of those works. The particulars of the boiler are as follow:—proof pressure per square inch, 128 lbs.; thickness of the plates, $\frac{9}{20}$ inch; number of the tubes, 125; internal diameter of the tubes, $1\frac{3}{5}$ inch; length of the tubes, 9 feet 7 inches; heating surface of the fire-box, 46·5 square feet; heating surface of the tubes, 487 square feet; total heating surface, 533·5 square feet; capacity of the boiler, 407 gallons. The fire-box is widened out towards the interior to give more grate area. There is a slope on the top of the fire-box from front to rear of 1 in 28, so that the top is level when the engine is descending the same gradient. This is done to avoid the risk of burning the top of the fire-box when the engine is about to descend, as happened once at Berzeko. There are two pumps, and one Giffard's injector. The tanks have a total capacity of 1,060 gallons. The boilers are able to generate steam very rapidly, owing principally to the great fire-box surface (more than one-twelfth of the whole), as well as to the short length of the tubes. The dimensions of the cylinders are—diameter, $13\frac{3}{4}$ inches; length of stroke, 18 inches.

The frame is composed of two side beams of plate iron $8\frac{7}{10}$ inches by $\frac{4}{5}$ inch. The overhang in the front is 6 feet 4 inches, in the rear 8 feet $\frac{1}{2}$ inch. The entire width of the frame is 7 feet $6\frac{1}{2}$ inches. The length between the buffers is 23 feet 9 inches. The centre of the boiler is 5 feet 1 inch above the rails, and the top of the chimney is 10 feet. The transverse beam in front is of cast iron, in the rear of wrought-iron plate. The axis of the traction bar is 2 feet $2\frac{1}{2}$ inches above the rails, and the working

deflection allowed to the traction spring is 2 feet $2\frac{1}{5}$ inches. The wheels are of wrought iron, the tires of Krupp steel. The outside diameter of the tire is 2 feet $10\frac{1}{4}$ inches, the least thickness is 2 inches, and the width 5 inches. The outside diameter of the flange is 3 feet. The distance between the leading and the middle wheel is 3 feet $8\frac{1}{2}$ inches, between the trailing and the middle wheel 3 feet $6\frac{1}{4}$ inches; the wheel base between the centres of the leading and trailing wheels 7 feet $2\frac{3}{4}$ inches. The wheel base, including flanges—a point of importance with reference to sharp curves—is 8 feet $4\frac{3}{4}$ inches. The play between the flanges and the rails is 1 inch on the straight; but round the curves the gauge is widened $1\frac{1}{4}$ inch. With this allowance, the whole wheel base may be inscribed in a curve of 197 feet, on the supposition that the bearings have no play on the axles, and that the system is perfectly rigid. In this case, when the middle and trailing wheels both touch the rails, the left leading wheel will have a play of $\frac{1}{5}$ inch, and the right leading wheel of $\frac{3}{4}$ inch. This was judged insufficient, and to remedy the defect it was decided to give a play of $\frac{2}{5}$ inch to the bearings on the front axle. The wear of the tires, and especially of the flanges, has been very great. The tires of one locomotive were rendered unfit for further use after a life of 12,500 miles. If they could have been turned the locomotive would probably have run as far again, but the workshop at Ergastiria was not provided with the requisite machinery.

This excessive wear shows the necessity of giving to the leading axle a play equal to 1 inch,—which would allow the middle wheel to press against the outside, whilst the trailing wheel pressed against the inside rail,—and of changing the point of attachment of the inside bar. The maximum weight of the engine and load being $22\frac{1}{2}$ tons, and the mean weight 21 tons, the distribution of the maximum load, ascertained by trial on a weighbridge, is—on the leading wheels, 7·26 tons; on the middle wheels, 7·64 tons; on the trailing wheels, 7·69 tons. This satisfactory result was obtained by using a cast-iron transom in front. The distribution is of course subject to great variations when the engine is at work, owing to the motion of the water in the tanks and in the boiler. In going up the sharpest gradient the weight of water displaced from front to rear or 'vice versâ' is about 700 lbs. This defect cannot be remedied. Round the sharpest curves the cant throws the water from the upper tank into the lower, and causes a maximum displacement of the load from one side to the other of about 500 lbs. This defect can easily be remedied by providing the pipe connecting the two tanks with a stop cock, which should always be closed except during the filling of the boiler or the tanks. On the section between Ergastiria and the summit, the ruling gradients are 1 in 28 and the curves are 200-feet radius; between the summit and Berzeko the gradients are 1 in 38 and the curves 230-feet radius. Thus the actual results confirm the truth of the theoretical rules of construction, the pressure in the boiler being about 128 lbs. per square inch. The engine works on

the first section with an admission of 30 per cent., on the second with an admission of 30 to 40 per cent.

The consumption of coal, whilst the engine is performing the double journey, is 337 lbs. To this must be added, 1st, coal used in getting up steam, 176 lbs. a day, or 60 lbs. per journey; 2nd, 66 lbs. of coal per journey burned during the descent of the gradients, the long stoppages, and the shunting. The total consumption of coal for the run of 11·13 miles is therefore 463 lbs., or 41·6 lbs. per mile. Such results may be obtained by skilful engine-drivers, with engines well designed and kept in good order. In practice the ordinary consumption is 53 lbs. per mile, because the pressure in the boiler only averages about 113 lbs. per square inch.

The line of Mokta-el-Hadid, constructed to convey the products of the iron mines from Mokta-el-Hadid to the port of Bona, traverses a slightly undulating country, the steepest gradient being 1 in 117, and the sharpest curve 820-feet radius. The gauge is 3 feet $3\frac{1}{4}$ inches, the width of the formation, exclusive of the side ditches, being 23 feet. The original Vignoles rails, of wrought iron, 34 lbs. to the yard, at £9 16*s.* per ton, have been replaced by Bessemer steel rails of the Ergastiria pattern, costing at Bona £11 18*s.* per ton. The cost per mile of the original road when ballasted was £1,191. The five locomotives are six-wheeled coupled tank engines, weighing 16 tons when empty, and $20\frac{1}{2}$ tons when loaded. Their cost, erected at Bona, was £1,244. Each train consists of forty mineral wagons, two carriages, and a break van. The gross load, including that of the engines, is 310 tons, the useful load 200 tons; the average speed is $10\frac{1}{2}$ miles per hour. The ordinary number of trains is seven per day, which represents a transport of 1,400 tons of ore from Mokta, with a consumption of about 24 lbs. of coal per mile.

Thus a great amount of traffic may be carried over a narrow-gauge line, when the gradients and curves are easy; while the line of Ergastiria shows, that steep gradients and sharp curves may be used to surmount high summits. The diminution of the load in the ascent need not prejudice the development of the traffic, if the gradients on the other parts of the line are easy, since an extra engine can be employed. A speed of from 18 to 22 miles per hour round curves of 394-feet radius, and of from 9 to 12 miles per hour round curves of 330-feet radius, may be adopted with safety, and without involving undue wear of the tires and the road. Including land and the building of simple stations, the cost of construction need not exceed £4,000 per mile, or with £1,400 for rolling stock, £5,400 a mile. The working expenses may be considerably reduced by adopting stations only at the most important points, and elsewhere simple stopping places for the issue of tickets by the guard, by abolishing night traffic, and, lastly, by limiting the speed to 22 miles per hour for passenger trains, a few only of which should be run on the important lines, while that for mixed trains should not exceed 12 to 16 miles an hour. This speed admits the

use of light, cheaply constructed rolling stock, in which the ratio of the useful to the dead load is great.

The Author also describes the railways of Rochebelle, of Cessous and Trébiau (Gard), and of St. Léon, between the bay of Madeleine, in the gulf of Cagliari, and the iron mines of the same name. Their details are similar to those already given, while on the latter railway there is this peculiarity, that from St. Lucia to Madeleine (about 6 miles) the sleepers consist of two wrought-iron shoes with the chairs riveted to them. The shoes are $\frac{1}{5}$ inch thick, $6\frac{1}{4}$ inches wide, and 10 inches long, the extremities being bent downwards at right angles. The shoes are tied together by a steel T iron $1\frac{3}{4}$ inch in height by $\frac{1}{6}$ inch thick, attached to each T iron by a single rivet. They weigh $20\frac{1}{2}$ lbs. without, and $39\frac{1}{2}$ lbs. with the chairs, and cost 6*s*. 8*d*. each. The engines are four-wheeled, weigh 5 tons empty, and $6\frac{1}{2}$ tons loaded, which gives for the maximum load on a single chair $1\frac{3}{5}$ ton. The area of the shoe being only 62 square inches, the pressure per square inch on the bearing surface of the ballast is 54 lbs., while on ordinary lines it rarely exceeds 34 lbs. The T-iron tie, on account of its weak section, twists and destroys the gauge. Ordinary sleepers, in addition to their greater bearing surface, assist in keeping the road in position by their mere weight. The metal cross-sleepers, on account of their lightness and the above defects, have been replaced in the curves; they will probably not be efficient in any position.

W. D.

Locomotive Engines on Inclined Planes. By M. Le Chatelier.

(Bulletin de la Société d'Encouragement, No. 1, 1874, pp. 6–18.)

The Author[1] enumerates three systems for conveying trains up steep gradients, namely, fixed engines working endless ropes to which the vehicles are attached; the atmospheric system; and haulage by locomotives. It appears that in general—setting aside special circumstances which permit of water power being utilised—the third system is preferable, if the first cost and the subsequent maintenance be considered together. The object of this memoir is not to discuss the comparative merits of the different systems, but to point out the extent to which the last of them can be carried, and to explain the principles which ought to govern its application.

Under ordinary conditions, locomotives are capable of developing great power, because their parts move at a high speed, and their

[1] In a footnote the editors of the "Bulletin" state that the memoir was written by the late M. Le Chatelier, in 1852, for the private use of his friend, M. Petin, who had at that time been consulted by the Italian Government respecting the construction of railways, and that the views expressed in the memoir having been borne out by subsequent experience, it would no doubt be read with interest.

boilers, if properly proportioned, have large steam-producing capabilities. Thus the goods engines in use on the Northern Railway of France, when running with a full load at a speed of 22½ miles per hour, develop 600 HP. The utmost power, however, can only be obtained at a maximum speed, for the work done at each stroke of the pistons remaining sensibly the same, the power is, as it were, dependent upon the number of strokes made per minute. But in constructing an engine to take a maximum load up an incline, the first thing is to reduce the speed, and thus to diminish the power of developing a large amount of force. It is true there are certain countervailing advantages, but these do not compensate for the decrease in force caused by the diminished piston speed. The advantages are the lessening of the resistances to the movement of the train, and the obtaining of a higher pressure of steam in the cylinders, owing to the greater time allowed for its traversing the passages. In this way the engine is made to exert its maximum tractive force, but the actual power developed is reduced. If, however, the proportions of the engine are not pre-determined, it is possible, in a certain degree, by reducing the diameter of the wheels, to combine the slow movement of the train with a high speed of pistons, thus obtaining the maximum development of power.

To augment the tractive power of a locomotive, however, it is not merely sufficient to diminish the diameter of the driving wheels; it is also necessary to increase the load upon those wheels in the inverse ratio of their diameter. Moreover, as the load upon the rails cannot be indefinitely augmented, it is necessary to multiply the number of points upon which it is carried. The conclusion is thus arrived at that, to work steep gradients with locomotives, the latter must have wheels of small diameter, so as to give a high piston velocity with a low speed, the wheels must be increased in number in proportion to the total load to be carried, and, lastly, the cylinders which give motion to each pair or group of wheels must have dimensions proportioned to the adhesion which those wheels will possess.

For working steep gradients, M. Le Chatelier proposes to employ engines weighing from 20 to 25 tons, including their fuel and water, to give to the wheels of these engines the smallest possible diameter, and to reduce the speed to from 9½ to 12½ miles per hour, preserving at the same time a rate for the driving wheels of two to three revolutions per second. The engines should be fitted with break shoes acting directly on the rails, and if the nature of the line or the state of the rails require it, the trains should be taken up by two or, if necessary, by three such locomotives, placing one at the end of the train during the ascent. During the descent the engines should be all at the head of the train, thus replacing the special break wagons otherwise required.[1]

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[1] For further information concerning the proportions of the engines he proposes, M. Le Chatelier refers to the "Comptes-rendus de la Société des Ingénieurs Civils." 1852, vol. v., p. 341.

The Author next considers the case of an incline of 1 in 33, up which it is desired to take trains of twenty wagons weighing $7\frac{1}{2}$ tons each. To furnish the tractive force, it is proposed to use two 25-ton locomotives, each having 15-inch cylinders, $17\frac{5}{16}$ inches stroke, and possessing 673 square feet of heating surface, the boilers being loaded to a pressure of 90 lbs. per square inch. The resistance of the whole train, including the engine, is calculated at 18,960 lbs. The consumption of these locomotives is estimated at 70·4 lbs. of coke and 493 lbs. of water per mile; while 1 ton of coke and 4 tons of water are deemed sufficient for a run of $12\frac{1}{2}$ miles. Adding to these 5 tons the weight of the tanks and coke boxes at say 1 ton, there would thus remain 19 tons for the net weight of each engine, this weight corresponding fairly with the other proportions. The diameter of the wheels could scarcely be less than $27\frac{1}{2}$ inches, or the connecting rod ends would project below the tread of the wheel; each engine ought to be mounted on either two or three pairs of wheels, according to the load the rails could carry, and according to the nature of the line.

M. Le Chatelier allows that when gradients are worked in the way proposed, namely, by grouping the engines at the head of the train to regulate the descent, inconvenience may arise from the trains in one direction not corresponding with those in the other, thus causing the engines to run a certain distance "light"; but this inconvenience can be diminished by providing suitable break power, so that the engines need not always descend the inclines with the trains; while the delays from this cause have an equivalent when the atmospheric system is adopted, as the trains must then in their ascent be divided into parts. With either system the descent of the trains must take place at a slow speed.

Steeper gradients—say, for example, of 1 in 20—could be similarly worked by locomotives, the wheels being reduced to about 2 feet in diameter. If this reduction in the size of the wheel should be objectionable on the score of the head of the connecting-rod not clearing the ballast, the stroke must be shortened, and the diameter of the cylinder proportionately increased. Thus modified, two locomotives of the weight above given would take thirteen wagons, weighing $7\frac{1}{2}$ tons each, up a gradient of 1 in 20, while, without any alterations in their dimensions, they would be capable of taking ten such wagons up a gradient of 1 in 20 at a speed of $12\frac{1}{2}$ miles per hour.

In the event of the atmospheric system being adopted on a gradient of 1 in 20, the tube, if worked with a vacuum of $\frac{3}{4}$ atmosphere, would have to be $23\frac{5}{8}$ inches in diameter to enable five wagons to be taken up at once, while for trains of thirteen or fourteen wagons the diameter of the tube would have to be increased to 39·3 inches (1 mètre). It must be remembered also that a very considerable part of the load in a train on the atmospheric system would arise from the special vehicle, which would have to be provided at the head of the train, and from the break wagon at the rear. With the large tubes difficulties of construction and of

maintenance would be out of all proportion to the amount of traffic.

In the case of a line destined specially for merchandise traffic, and on which the speed can without inconvenience be reduced to 6 miles per hour, M. Le Chatelier, referring to the fact that rack rails have been used in England, and in one instance at least in the United States, considers that such a rail laid between the ordinary rails, and into which should gear a toothed wheel driven by the engine, could with advantage be employed. With engines of the general dimensions above stated, driving a pinion $13\frac{3}{4}$ inches in diameter, a tractive power of 8·3 tons would be developed by each locomotive, so that one engine could take a load of thirteen wagons up an incline of 1 in 20. For passenger traffic he proposes that the ordinary engines should remain attached to the train, and that a rack rail engine should be employed as a bank engine, and placed at the rear of an ascending or at the head of a descending train. In the latter position it would form a perfect break. Such an engine should be fitted with small auxiliary cylinders, acting on the ordinary wheels, so as to enable it to be readily moved about on those parts of the line where the rack rail is not laid down.

M. Le Chatelier remarks that the principles he has enunciated do not appear to have been understood by the engineers who settled the terms of the Semmering competition, nor by the constructors who furnished the engines; the locomotive 'Bavaria' and its rivals having been made with wheels of too great diameter, and the whole of the working gear having to be proportionately heavy in consequence. The 'Bavaria' possesses less tractive power than a pair of such engines as have been described, although weighing half as much again. The two engines could be coupled back to back, and driven by one engine driver, one assistant driver, and one fireman.

As regards cost of working, the Author states that in 1857 the expense of locomotive traction on French railways was given by the formula $P = 0{\cdot}475 + \frac{F}{100}$, in which P is the cost in francs per kilomètre, and F the price of coke in francs per ton.[1] Considering that in the case of the engines proposed, for working heavy gradients, the wheels will make twice as many revolutions per mile as those of ordinary engines, M. Le Chatelier assumes their working expenses to be double, and, with coke costing 40*s.* per ton, he calculates the expenses at 32*d.* per mile, or a maximum of 40*d.* per mile, including interest on the cost of the engines, and the exceptional repairs which bank locomotives require when working under unfavourable conditions.

Altogether, M. Le Chatelier considers that whatever system is ultimately adopted for working a mountain railway, locomotive haulage should first be tried. The locomotives thus provided are

[1] If P be taken as the cost in pence per mile and F the price of coke in shillings per ton, the expression becomes $P = 7{\cdot}6 + \frac{F}{5{\cdot}27}$.

useful during the formation of the line; they will serve for carrying on the traffic in the event of any stoppage of the stationary engines, supposing these to be ultimately provided; while, besides this, when not required on the mountain section, they can be turned to useful account on other parts of the line. For the traffic over a line between Modane and Susa (with a tunnel through the Mont Cenis), as laid out by the Chevalier Maus, with gradients varying from 1 in 100 to 1 in 28½, over a length of 22½ miles, and a gradient of 1 in 52·6 for a length of 7½ miles in the great tunnel, it is considered by M. Le Chatelier that three passenger trains and four goods trains each way per day will suffice, and that these trains could be so arranged that in the case of only one of the passenger trains each way per day would it be necessary to run a "light" engine over the line. For working such traffic the locomotive expenses are calculated by M. Le Chatelier at £33,490 per annum, and it is considered that the work could be done by twenty-four locomotives, of which the cost is estimated at £50,000. If the line were worked by fixed engines and ropes on M. Maus's system, ten fixed engines, costing with the ropes £20,000 each, would be required, while the cost of maintenance of the cables is estimated at £320 per mile per annum, and the cost of repairs of engines, enginemen's and breaksmen's wages, &c., at £1,600 to £2,000 per annum. If to these expenses be added the interest on the capital expended on fixed plant, it will be seen on which side the advantage lies, even if the fixed engines be worked by water, and the motive power be thus furnished gratuitously. The atmospheric system being even more costly, has a still more doubtful application.

In conclusion, M. Le Chatelier considers the Piedmontese Government should build a pair of locomotives of moderate weight, with very small wheels, such as he has recommended, and also give a fair trial to the railway with a rack.

W. H. M.

Common Error in ascertaining Locomotive Adhesion available for the Traction of Trains.

By J. Moschell, Engineer in Chief of the District Railway of the Jura.

(Annales du Génie Civil, March 1874, pp. 145–149.)

The Author states that ordinarily, after having determined the total tractive force which can be produced by the adhesion of any particular locomotive on the rails, engineers deduct therefrom a certain proportion, as being required for the locomotive itself, and treat the residue only as available for overcoming the resistance of the tender and of the other parts of the train. The Author is of opinion that engineers make this deduction on the basis that the friction between the wheels and the rails has to overcome the resistance of all the moving parts of the

engine, and he enters into elaborate arguments with illustrations to show, that it is the steam which has to overcome this resistance, and that the adhesion of the engine is not called upon to play any part in the matter.

Further, he directs attention to the fact that by coupling a second pair of wheels in a locomotive, so as to turn them into drivers, not only is the adhesion available for traction increased by the effect of the weight upon the other pair of driving wheels thus brought into play, but that the adhesion formerly employed to overcome the journal friction of these wheels is no longer necessary. By assuming a proportion between the diameter of the wheel and that of the journal of 7 to 1, and a load of 10 tons upon the pair of wheels, with a friction on the journals of $\frac{1}{20}$, he proves that 160 lbs. out of the whole adhesion, required to overcome the friction of the journals, are now set at liberty for the purpose of assisting in drawing the train; and he attributes to this fact the explanation of a matter observed by M. Flachat, viz., that the adhesion of two pairs of coupled wheels was a greater percentage of the insistent weight than that afforded by the adhesion when one pair of driving wheels only was employed. M. Flachat explained this discrepancy by assuming that the wheels were not truly of the same diameter, and that thus there was a slight grinding action which increased the adhesion. The Author, however, believes that he has found the solution in dispensing with the journal friction of the one pair of wheels.

B.

Locomotive without Fire. By M. S. Pichault.

(Annales Industrielles, June 14, 1874.)

Among the applications of mechanical force to the traction of vehicles on tramways or roads, a fireless locomotive has been employed by Mr. Lamm on the New Orleans tramway, since the spring of 1872, to which he gives the name of thermospecific engine. It consists of an ordinary steam-engine mounted on the tramcar, or on a separate truck, with a boiler having no furnace, and therefore smokeless and less liable to explode. This locomotive is supplied with water from certain stationary boilers along the route, heated to a temperature corresponding to 12 or more atmospheres of steam pressure. As this heated water gives off steam to the engine, its temperature, and the corresponding pressure of the steam, continually diminish, until a new station is reached and a fresh supply of hot water taken in. In order to judge of the quantity of work which such a boiler can give out, the Author obtains from the principles of thermodynamics:—

$$T = 90{,}000\ V\ (t_0 - t_1) \text{ in French units}$$
$$= 10{,}000\ V\ (t_0 - t_1) \text{ in English units.}$$

V being the capacity of the boiler in cubic mètres or feet;
T, the work produced during the falling of the pressure in kilogrammètres or foot-pounds;
t_0 and t_1, the initial and the final temperatures in degrees centigrade or Fahrenheit.

Modified, to allow for losses by radiation, conduction, leakage, &c., the formula is given as

$$\begin{aligned} \mathrm{T}\,u &= 22{,}500\ \mathrm{V}\ (t_0 - t_1) \text{ in French units} \\ &= 2{,}500\ \mathrm{V}\ (t_0 - t_1) \text{ in English units.} \end{aligned}$$

As an application of the above, let $t_0 = 190°$ cent. or 374° Fahr., which corresponds to a pressure of 11 atmospheres, and $t_1 = 153°$ cent. or 307°·4 Fahr., which corresponds to 4 atmospheres, then

$$\begin{aligned} \mathrm{T}\,u &= 22{,}500\ \mathrm{V} \times 37 \quad = 830{,}000\ \mathrm{V}, \\ \text{or } \mathrm{T}\,u &= 2{,}500\ \mathrm{V} \times 66{\cdot}6 = 166{,}500\ \mathrm{V}. \end{aligned}$$

That is to say, each cubic mètre of water under these conditions can furnish 830,000 kilogrammètres of work, or each cubic foot can furnish 166,500 foot-pounds. If the journey lasts for an hour, this is equivalent to about 0·08 HP. (English) per cubic foot, or about 3 HP. (French) per cubic mètre of water. The experiments at New Orleans are examined in the original Paper by this formula, and are found to agree with it.

Though the application of this source of power is comparatively easy on tramways, it is less so on railways, because a boiler, large enough to hold the water usually carried by a locomotive and tender, would scarcely contain sufficient to produce a motive power of 60 HP. (French); while ordinary locomotives attain almost 600 HP. To diminish the size of the boiler, the distance between the replenishing stations may be shortened; but there will remain the inconveniences inherent to the variation of pressure within great limits, and to the variation of adhesion.

For the weight of steam μ, formed while the temperature passes from t_0 to t_1, the Author obtains the formula:—

$$\mu = 1000\ \mathrm{V} \times \frac{0{\cdot}7882\ (t_0 - t_1)}{575 - 0{\cdot}7882\ t_1} \text{ in French units,}$$

$$\mu = 62{\cdot}5\ \mathrm{V} \times \frac{0{\cdot}7882\ (t_0 - t_1)}{1036 - 0{\cdot}7882\ (t_1 - 32)} \text{ in English units.}$$

Adopting the same temperatures as before, $\mu = 64\ \mathrm{V}$ or 4 V. That is to say, each cubic mètre of water has given off 64 kilogrammes of steam; or each cubic foot has given off 4 lbs., or about one-fifteenth of its weight. The number of thermal units to be taken from a stationary boiler, to recharge the locomotive when the temperature has fallen from 190° centigrade to 153° centigrade by giving off steam, is the difference of thermal units in the boiler under these two conditions of temperature. It must be

remembered that, besides the fall of temperature, 64 kilogrammes of water in the form of steam have been abstracted per cubic mètre. It is shown in the original Paper that about 48,000 French thermal units have to be supplied per cubic mètre of capacity of the thermospecific boiler, or 5,270 English thermal units per cubic foot.

The restoration of lost thermal units is effected in practice by connecting the stationary and locomotive boilers, and allowing the heat to pass from one to the other, taking care to have a proper arrangement of level between them, and to have the stationary boiler much larger than the locomotive boiler, as the temperature of the former will otherwise be considerably lowered by the abstraction of so much heat.

It is calculated, in the original Paper, that if compressed air be stored up instead of hot water, each cubic mètre of compressed air between 11 and 4 atmospheres of pressure can only give out 24,500 kilogrammètres of work; while, as shown above, each cubic mètre of water gives out 830,000 kilogrammètres, or thirty-eight times as much. With fifteen thermospecific engines an economy was effected of 50 per cent. over the use of horses.

S. D.

On the Tendency of the Reversing Lever of Locomotives to "return suddenly" when being pulled over. By A. Balguerie.

(Bulletin de la Société d'Encouragement, Feb. 1874, pp. 73–85, 1 pl.)

Referring to the well-known tendency of the reversing lever of a locomotive, when disengaged, to fly into full gear, more particularly when the engine is reversed with full steam on,[1] M. Balguerie investigates the reaction caused by the obliquity of the link with respect to the valve-spindle, as the cause of such tendency, and calculates approximately the force with which the reversing lever is urged to move. He selects for investigation the valve-gear, or 'distribution,' of three classes of locomotives on the Midi railway, fitted respectively with Stephenson's link, Gooch's link, and Allan's link. These are well-known types, of which, in the first, the expansion-link is shifted vertically, whilst the valve-block is maintained in a fixed centre-line; in the second, the link is suspended from a fixed point, or is stationary, whilst the valve-rod link is shifted vertically; and in the third, both the expansion-link and the valve-rod sling are shifted vertically, in contrary directions, being suspended from the ends of a double lever worked by the reversing handle. M. Balguerie assumes, for simplicity, that

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[1] This relates to the practice on many continental lines of reversing the engine with full steam on, to obtain, on the Le Chatelier 'contre-vapeur' system, the arresting of the motion of the train. To absorb the heat developed in the cylinders by this reversal an injection of water is provided.—Sec. Inst. C.E.

the chord of the arc of the expansion-link may be substituted for the arc; and, putting α for the angle of inclination of the chord with a line perpendicular to the centre-line of the valve-spindle, and R for the resistance of the valve to be moved, the component of this force tending to displace the slide-block in the link, is equal to R sin α. On the basis of Zeuner's formulæ, the Author, beginning with an example of the Stephenson link, calculates the values of R sin α, for fourteen points in the circular path of the crank, at equal intervals, commencing at the dead point of the crank, and on the supposition that the expansion-link is placed nearly in full gear, as follows:—

Angle of crank with the dead point.	Value of R sin α.		Angle of crank with the dead point.	Value of R sin α.	
° ′			° ′		
0 0	0·02465 R		210 0	− 0·1821 R	
30 0	− 0·1909 R		232 35	∓ 0·3104 R	(change of sign.)
52 35	∓ 0·3336 R	(change of sign.)	240 0	0·3433 R	
60 0	0·3521 R		270 0	0·4157 R	
90 0	0·4157 R		300 0	0·3679 R	
120 0	0·3679 R		330 0	0·2247 R	
150 0	0·2247 R		360 0	0·0246 R	
180 0	0·0246 R				

From this table it appears that the value of R sin α is generally positive: that is, it tends to drive the slide-block to the end of the link; but about the angles 30° and 210° the force is, for very short intervals, exerted in the contrary direction.

The above deductions apply to one link and valve-motion; for two, the efforts are so combined that the maximum united force to be opposed by the reversing lever takes place at the angle 48° 27′, and amounts to 0·5889 R. The Author estimates from these data that, when the working surfaces are in good condition, the oblique action of the slide-blocks produces a maximum force of about 1,100 lbs. (500 kilogrammes), which is equivalent to a resistance of from 20 lbs. to 22 lbs. (9 to 10 kilogrammes) at the handle of the reversing lever, the amount of which may at times be much increased:—for instance, when the engine is reversed with steam on and without the injection of water, extra resistance is caused by the slide-valve faces heating and gripping.

Proceeding with examples of the Gooch link and the Allan link, the Author summarises the results of his inquiry thus:—

	Angle of crank.	Maximum united disturbing force, at the slide block.
	° ′	
Stephenson link	48 27	0·5889 R
Gooch link	49 5	0·5318 R
Allan link	48 3	0·5542 R

In these three examples the angles of the eccentrics with the centre lines of the cylinders are nearly the same, 30° and 33°. In

another class of locomotive fitted with the Stephenson link, the eccentrics are keyed at an angle of 10° 30′, the reversing lever can be managed without the slightest difficulty, and the maximum deranging force is only 0·3932 R, or from 440 lbs. to 560 lbs. (200 to 250 kilogrammes). Now these engines are fitted with two counterweights, on the reversing shaft, of 330 lbs. each (150 kilogrammes), or together 660 lbs. (300 kilogrammes). From this total weight is to be deducted 110 lbs. to 130 lbs. (50 to 60 kilogrammes) for balancing the weight of the expansion-link, &c.; and the remainder is just sufficient to counteract the oblique action on the slide-blocks. Hence the facility with which the reversing gear is managed. There is the objection, however, that in backward gear the counterweights add to the labour of working the reversing lever, instead of diminishing it.

The Author concludes that the counterweights of locomotives, as usually proportioned, may be beneficially augmented, with a view to facilitate the working of the reversing lever.

D. K. C.

Breakage of Tires on the Moscow-Nishni Railway during the Winter of 1871–72.

(Journal of the Ministry of Ways and Communications, St. Petersburg, Dec. 1873.)

The following number of steel tires broke between the 29th of November, 1871, and the 10th of April, 1872:—Passenger engine tires, 5; goods engine, 22; tender, 9; passenger carriage, 10; goods wagon, 14; total, 60.

These had been made by the following manufacturers:—Krupp's Steelworks, Essen, 23; the Obuchof Steelworks, St. Petersburg, 14; Vickers and Co., Sheffield, 12; the Bochum Steelworks, Westphalia, 8; John Brown and Co., Sheffield, 3.

The percentage on the total numbers in use and bought from the above works was—

Name of Works.	Engines.			Tenders.			Carriages and Wagons.			Total.		
	Total.	Broken.	Per Cent.	Total.	Broken.	Per Cent.	Total.	Broken.	Per Cent.	Total.	Broken.	Per Cent.
Vickers .	231	9	1·9	94	2	2·14	1,662	1	0·07	1,987	12	0·66
J. Brown	..	..	..	..	..	..	2,170	3	0·14	2,170	3	0·14
Obuchof	..	..	..	..	..	..	3,418	14	0·35	3,418	14	0·35
Bochum	82	4	4·8	97	1	1·0	537	2	0·36	1,116	7	0·63
Krupp .	491	11	2·24	471	7	1·5	176	5	3·0	1,138	23	2·11

The number of breakages, according to the months in which

they occurred, was—November, 1; December, 3; January, 32; February, 19; March, 5.

They had run the following average number of English miles before breaking:—Bochum, 51,066; Krupp, 34,666; Vickers, 28,266; Obuchof, 27,066; J. Brown, 13,134.

The tires were turned inside before being put on the wheels at the Kovrof repairing shops belonging to the railway company, and their diameter when cold was, according to Krupp's rule, $\frac{1}{1600}$ smaller than the diameter of the wheel, say $\frac{1}{2}$ to 1 millimètre. They were heated to a dark brown colour, when their diameter was increased 7 to 12 millimètres, after which they were put on the wheels. The wagon tires were immersed in cold water; but the engine tires were cooled gradually, by pouring the water over them. The furnaces were of a square section, and observations showed that the tires were not heated uniformly over their whole circumference.

The breakage is assigned to the following causes:—

1. The strain on the tire from excessive contraction in cooling. The fracture is necessarily in the direction of the radius, and mostly along the bolt-holes if the metal is of uniform quality; any other direction shows that the metal is not uniform throughout. 2. Bad quality of the metal, as proved by a coarse-grained fracture, lacking uniformity. 3. The bolt-holes, particularly of countersunk bolts, are a great source of weakness. 4. Sometimes either the wheel or the tire is not turned exactly true, which causes unequal strains after it is placed on the wheel. If an iron tire is welded, when once broken it is scarcely possible to turn it true, and sometimes pieces of thin sheet-iron are placed between the tire and the wheel. The unequal tightening up of the bolts may injure the strength of the tire. 5. In a square furnace those parts of the tire nearest the sides are subject to greater heat than those opposite the corners, and when the tire contracts, the former are of course strained more than the latter. 6. Severe cold, below 10° Fahr., evidently has a marked effect upon hard steel and iron containing impurities, by considerably reducing their tensile strength. The frost not only increases the hardness of the road, but makes it uneven. It is a well-known fact that a clayey subsoil bulges out in cold weather. On the other hand, the carriage springs partly lose their elasticity. These combined causes produce severe shocks, which take effect upon a metal that has lost part of its strength, and the results are shown in the breakages per month. In January there are 52 per cent. of the whole number, against 31 per cent. in February. The frost affects steel more than iron. Eleven steel rails broke in a distance of 4 miles, while only twenty iron rails of middling quality broke in 100 miles, and none in 166 miles laid with Siberian rails, of which the metal is very pure and soft. 7. It is impossible to make the six coupled wheels of a goods engine of exactly the same diameter; and even if this were possible, they would wear differently in proportion to the weight upon them. The middle and trailing wheels will slip more than the leading wheels, and

in curves the slip will be greater still. The strain of this sliding friction upon the tires, particularly in cold weather, may cause breakage. On the Nishni railway twenty tires of goods engines broke, of which seven belonged to leading, five to middle, and eight to trailing wheels. In passenger engines, where only two pairs of wheels are connected, this friction is much smaller, and therefore causes fewer breakages. Only five tires of passenger engines broke—four on the middle, and one on a trailing wheel. The destructive effects of sliding friction in cold weather can also be traced on tender tires. One half of the break power, with the usual arrangement, acts upon the hind wheels, while the other half is expended on the middle and fore wheels; consequently the strain on the former is not only severer, but they also wear more quickly and show more places worn flat. Of ten broken tender tires five belonged to the hind wheels, three to the middle, and two to the fore wheels.

No breakages occurred on wheels of Mansell's pattern, owing, probably, to the softness and elasticity of the body of the wheel, which consisted of wood. Besides, the tires are fastened to the rim, not by bolts, but by rings on both sides, by which means the weakening effects of bolt-holes are avoided. If a breakage should nevertheless occur, the separate pieces of the tire would be held in place by the rings. Only in eighteen cases out of sixty-one could an opinion be formed of the fractures of the broken tires, because they were mostly rusted. Judging from the fractures, it is believed in eight cases the cause of breakage was bad metal; in seven cases, excessive strain in putting on the tires; and in three cases, indifferent quality of metal combined with too great wear. Fourteen tires were broken through the bolt-hole, and three through the screw-hole, the tires being fastened to the rim by screws from the inside of the rim.

The use of tires having a considerable degree of hardness (as from the works of Bochum, Krupp, and Vickers) is rather detrimental to iron rails; and it is probable that the saving derived from their longer endurance entails a heavier expense in the renewal of rails. The hardness of the tires therefore ought to be made dependent upon the hardness of the metal used for the rails. Iron tires injure the rails less, and are less liable to suffer from excessive strains, their metal being tougher, and admitting of a higher degree of elongation before rupture actually takes place.

On the Nishni line the tires are turned whenever the most worn places attain a depth below a true circle of 4—5 millimètres.

C. G. K.

On measures for protecting Railways from Snow, as adopted on American and European Lines. By Ernest Pontzen.

(Zeitschrift des Oest. Ing. und Arch. Vereins, No. 8, 1874, pp. 131–137, 3 pl.)

To escape the effects of a rigorous climate long deviations and tunnels at a lower level have frequently been made. But the highest regions are not always the most exposed to obstructions from snow, which are caused either through drifts or avalanches. The railways over the Semmering Pass, 2,892 feet (881·5 mètres) above sea level, and over the Brenner Pass, 4,485 feet (1,367 mètres), suffer little; whereas on the Parndorf Heath, 590 feet (180 mètres) above the sea, on the Marchfeld, 492 feet (150 mètres), and on the Wiener-Neustadt Plain, 919 feet (280 mètres), frequent interruptions in the traffic occur from the drifting of snow. The railway over the Karst (Carso), 1,968 feet (600 mètres) above the sea, is one of those lines of Central Europe most exposed to snowdrifts. Avalanches are easier to deal with, for the spots where they occur are known, and the line can generally be kept out of their reach.

In projecting a railway exposed to such contingencies, cuttings must be avoided; and even the snow from low embankments, when repeatedly swept by the plough, soon gets heaped upon both sides, and the conditions of a cutting are reproduced and cause drifting. This has been experienced on the Union Pacific railway, where the embankment was subsequently raised 3 feet for about 30 miles. Where cuttings are necessary, the usual protective works consist of fences, walls, or banks parallel to the line on the side of the prevailing winds.

The first things to be considered are the configuration of the country and the direction of the prevailing wind. The latter, however, as well as the angle at which it strikes the ground, may vary so much as to render it difficult to decide on what side of the line the works shall be erected. It may often appear advisable to have them on both sides, in which case other means are to be preferred. If the direction of the wind is pretty constant the problem is easy. When an obstacle is presented to driving snow, prisms are deposited before and behind it, the length of the one behind being sometimes five times the height of the obstacle, and the distance from the top of the cutting at which a fence or wall should be erected has to be calculated accordingly.

On the Karst railway, upright wooden fences and stone walls, with a minimum height of 16 feet 5 inches (5 mètres), were erected. On the Parndorf Heath, a bank 6½ feet (2 mètres) high was thrown up parallel to the railway. The fence adopted on the Pacific railway leans towards the line, but the upper part is inclined in a reverse direction, so as to divert the currents of wind upwards, and thereby to shelter a much wider strip of ground. The planks, moreover, are placed so much apart, that the wind blows between

them and prevents any great deposition of snow on either side. The fences are made in lengths of 16 to 20 feet, and can be removed when they obstruct cultivation, while they are sometimes set up in parallel rows, to prevent not only drifting of snow, but the rolling of large masses on to the line.

Fences or walls, when used on both sides of the line, must be carried up to a considerable height, as they are only serviceable so long as there is room for the snow to be deposited on both sides. Shelter against storms varying in direction, and against 'Schneewirbel,' or 'tourmentes,' so frequent in the mountains, is best provided in the form of roofs or galleries.

On the (temporary) railway over Mont Cenis, constructed on the Fell system, lengths of 4,484 yards (4,100 mètres) at the summit, of 3,390 yards (3,100 mètres) between Grand Croix and St. Martin, and at various other places, making together a total of 15½ miles (25 kilomètres), were covered. These galleries, with the exception of those spots where avalanches had to be guarded against, consisted of timber framing, boarded in. They had a clear height over the line of 12 feet 4 inches (3·75 mètres), and could bear the weight of 20 feet of snow. Some of the roofing was of corrugated iron. Ventilation was provided for by longitudinal openings at the top, or spaces were left between the boards at the sides, but, owing to the small height of the gallery, the air was very bad.

The Pacific railway is provided with 43½ miles (70 kilomètres) of snow galleries, of which the greater part is on the Central Pacific, the Union Pacific being sheltered chiefly by fences. In spite of the greater inclemency of climate of the Sierra Nevada no interruption to the traffic occurred, even for a day, from this cause during the winter of 1872–73; whereas, during the same period, the traffic of the Union Pacific was stopped for several weeks. The galleries have proved a perfect success. In the winter of 1866–67, during which time the works on the Pacific railway were in progress, observations were made on the snowfall by the Engineer, Mr. John R. Gilliss,[1] the results of which subsequently appeared in a report to the American Society of Civil Engineers. From November to June snow fell on forty-four days. The total depth was 44 feet 8 inches (13·6 mètres), the average depth on the ground during the eight months being 7 feet ½ inch (2·3 mètres). The pressure of the wind during the snowstorms reached 10 lbs. per square foot, while the lowest temperature during the winter was 5½° Fahr. The snow galleries are entirely of timber, and have an internal height of 23 feet 3½ inches (7·10 mètres). Along the ridge of the roof there are numerous small ventilating towers, provided with louvre windows. The boarding of the sides of the gallery is, about the middle of its height, carried a short way down the inclined struts, while the

[1] *Vide* "American Society of Civil Engineers. Transactions," vol. i. (1872), pp. 153–171.

lower and perpendicular boarding ends at a short distance from the ground, whereby perfect ventilation is secured. During the summer, lengths of the boarding can be removed to let in light and air. To prevent fires, which have been very destructive, the roofs are being lined with corrugated iron, and steam fire-engines on trollies are kept in readiness at every station.

At those parts of the Mont Cenis railway, along the steep sides of the mountain liable to avalanches, the line was arched over. The covered ways had a width of 13 feet 1½ inch (4 mètres), and a thickness at the crown of 23½ inches (60 centimètres), the angle between the arch and the mountain slopes being filled in with a backing of earth and stone. Similar arches, with openings at intervals on the valley side to admit light and air, have existed for some time on the road over the St. Gothard Pass and elsewhere.

On the Pacific line the sloping roof of the galleries abutted against the side of the mountain at a steep angle. The ventilation of such galleries is better than that of masonry arches, as they inclose a larger volume of air, and they were undoubtedly, in the case mentioned, erected more quickly and at much less cost than the arched covered ways of the Mont Cenis line. On European mountain lines, where a supply of timber is always at hand, a consideration of the relative advantages of a cheap or a durable structure will probably lead to the use of timber.

By the adoption of the means described, snowdrifts and avalanches need cause no great interruption of traffic; and the long and expensive tunnels, to avoid the higher regions and escape snowstorms, may be considered for the future as unnecessary.

H. D.

The Financial Statistics of European Railways from 1855 *to* 1873.

By Dr. G. Stürmer, Director of the Realschule at Bromberg.

(Zeitung des Vereins Deut. Eisenbahnverwaltungen, Nos. 42 & 47, 1874.)

The Author gives, in a tabular form, particulars of the number of miles open, cost of construction, receipts, expenses, percentage of expenses as compared with receipts, profits per mile and percentage of profit on outlay; but the returns are not in all cases complete for the period named.

In the Empire of Germany there were, at the end of 1872, 14,077 miles open, the average cost of construction having been £18,233 per mile. The net revenue was 52·2 per cent. of the gross receipts, whilst the profits on outlay amounted to 6·6 per cent. The most remarkable feature of the German returns is the great increase in the receipts per mile, which have nearly doubled during the period indicated. With regard to the Austrian railways, which embraced a total length of 8,734 miles at the end of 1872, the average cost of construction was £20,512 per mile, and the profits showed a gradual decrease from 9·8 per cent. in 1868 to 6 per cent. in 1872.

This, however, is accounted for by the recent addition of a large number of new lines, the traffic on which has not, as yet, been fully developed. Great Britain had 15,813 miles open at the end of 1872, the average cost of construction being £35,984 per mile, as compared with £35,703 in 1855, or nearly double that of the German lines. The receipts per mile exhibited a steady increase from 1855, a slight falling-off being noticeable in 1869 and 1870; but as the Author points out, the rise was not nearly so rapid as on the German railways. The complete French returns do not come later than the year 1869; but the total length of lines open at the end of 1873 amounted to 11,538 miles (besides 700 miles of local railways), the average receipts being £2,697 per mile. The Belgian railways had at the end of 1872 an extent of 962 miles only, the average cost of construction being apparently higher than in Great Britain; but this is due to the manner in which the returns are made out, the charges for maintenance and renewal being added year by year to the original cost. The profit on capital reached 8·1 per cent. The Dutch railways are remarkable for the smallness of the receipts, which are about one-third those of the German lines. Taking the Central railway of Switzerland as a representative line for that country, the receipts and profits show a very marked increase. In Sweden the receipts per mile are very small; but in consequence of the low cost of construction the railways yielded a return of 6·3 per cent. on the private lines, and of 3·3 per cent. on the State lines. The Russian statistics are very imperfect; but it appears that at the end of 1873, 10,140 miles were open. The cost of constructing the 8,670 miles open in 1871 was £21,846 per mile, the receipts being £2,098 per mile during that year. Taking the whole of the European railways, the receipts during the year 1873 approached £2,438 per mile; the working expenses were about half the gross receipts; whilst the returns on capital were between 5 and 6 per cent. For purposes of comparison the Author gives some particulars of the United States railways. At the end of 1873 there were 71,569 miles open, the cost of construction being £11,314 per mile, calculated on the returns from 54,000 miles only, particulars of the remainder not being obtainable. The dividend on capital of the entire American railway system reached 6·1 per cent.

R. B. P.

The Hanoverian Machine Company's Works at Linden.

By Herr Richard, Assistant at the Polytechnic of Hanover.

(Zeitschrift des Arch. u. Ing. Vereins, Hannover, xx., No. 1, 1874; cols. 63–76, 4 pl.)

The machine manufactory at Linden was established in the year 1840 by George Egestorff, one of the industrial pioneers of Hanover. Towards the end of 1868 the works were purchased by Dr. Strousberg of Berlin, and in 1870 they became the property of a joint-

stock company called "The Hanoverian Machine Works Company." They comprise an iron-foundry capable of turning out from 3,440 to 3,981 tons (3½ to 4 million kilos.) per annum; turnery and fitting-shops; erecting shops sufficiently spacious to allow of the simultaneous erection of thirty-six locomotives and twenty-four tenders; boiler-shops, capable of producing from twenty to twenty-two locomotive boilers and a similar number of tenders per month; wheel-works which supply wheels for two hundred locomotives and tenders per annum; smiths' shops and steam-hammer sheds; brass-foundry, coppersmiths' workshop, &c. The works have railway communication with the Hanover and Altenbeken Line at Linden Station, and they cover a total area of nearly 50 acres (19·7 hectares). The motive power is supplied by sixteen steam-engines of a united force of 350 HP. There are sixteen steam-hammers and twenty-six boilers, about one hundred and ninety smiths' forges, and thirty-four furnaces of various kinds. Two locomotives are kept in constant employment in the works, and the number of machine tools is about eight hundred. Three thousand two hundred workmen and two hundred and fifty clerks and superintendents are employed. At the present moment the establishment is capable of turning out from two hundred to two hundred and fifty locomotives per annum, in addition to which machinery of the annual value of from £30,000 to £42,500 (200,000 to 300,000 thalers) is produced. The manufacture of locomotives, which was commenced in the year 1846, has increased of late years with great rapidity. The hundredth locomotive was made in 1856; No. 200 was delivered in 1862, and No. 300 in 1868; whilst during the months of March–June 1873, no less than one hundred were manufactured; bringing up the total number made since the commencement in 1846 to one thousand. Under the name of "Bismarck" No. 1,000 was shown at the Vienna Exhibition. The majority of the locomotives were for Germany, but ninety have been sent to Russia, fifty to Turkey, seventy-five to Roumania, forty-five to Austria and Hungary, and a few to Spain, Holland, and other countries. The railway within the works is about 4·34 miles (7,000 mètres) in extent, and its course is laid down on the plans of the workshops which accompany the memoir. The workshops are principally warmed by steam, in some cases taken direct from the boilers, while in others the waste steam is utilised. In some of the shops the steam circulates through the hollow columns which support the roof, but in others coils are used. The water-supply is obtained from the river Ihme, the necessary works having been constructed jointly by the company and two neighbouring factories. The reservoir is situated at a height of 88 feet (27 mètres) above the level of the works; the quantity consumed by each establishment being measured by meters. There are, in addition, several elevated reservoirs in different parts of the works which are always kept full, to form a reserve, and are fitted with a self-acting arrangement of valves, so as to discharge the water into the supply-pipes whenever the pumping apparatus

stops or the supply in the elevated reservoir fails. The workmen's dwellings, which occupy an area of about 7·8 acres (31,500 square mètres), form a striking feature of the establishment, the number of inhabitants being about three thousand, including the workmen's families. The remainder of the memoir is occupied by a description of the arrangement of the smiths' shops, turnery, and grinding apparatus. Details of the works, of the machinery employed, and of the different apparatus are given in the drawings which accompany the Paper.

R. B. P.

Experiments on the Laws of Filtration. By Paul Havrez.

(Revue Universelle des Mines, May–June 1874, pp. 469–551, 3 pl.)

The Author's investigations as to the rapidity of filtration of water through sand, wool, &c., resulted in ascertaining and measuring the influences which may modify the flow of water. The influences which are exerted in all cases of filtration are: the pressure and temperature of the water, the thickness of the filtering medium, compression in the case of fibrous filters, and the size of the grains and their mixture in the case of a filtering medium analogous to sand. The influence of obstructions due to the dirtiness of the filter depends on circumstances too variable to be taken into account. The delivery of a filter per square mètre per twenty-four hours is equal to 2 cubic mètres multiplied by the pressure of water in mètres, divided by the thickness of the filtering medium in mètres. An application of this formula is made to existing filter beds, including those at Southwark and at Chelsea.

The first experiments, for ascertaining the influence of a head of water on the delivery, led to the following results:—The delivery increases in a higher ratio than the square root of the pressure due to the height (Torricelli's law); the delivery increases in direct ratio to the height of the column of water above the filter, admitting a previous initial delivery due solely to the pressure of the water held by the filtering substance itself; for every increment of 5·315 inches (135 millimètres) of height in the column of water above the filter, the co-efficient of the increase of delivery is constant, and in the case of a filtering substance 8·662 inches (22 centimètres) thick, is equal to 0·106 pint (6 centilitres) for sand, to 0·528 pint (30 centilitres) for compressed wool, and to 0·792 pint (45 centilitres) for wool only slightly compressed.

The subsequent experiments were made with graduated transparent glass cylinders, 3·28 feet (1 mètre) high, with the ends perfectly level, the filtering substances being kept in place by a thick double cloth tied tightly under the bottom of the tube. This apparatus presented no other obstacle to the running of the water than the layer of filtering substance; it permitted experiments to be made at all temperatures, and the thickness of the filtering medium to be measured exactly.

In these experiments, sand is taken as the type of pulverulent substances; but an unexpected difficulty was encountered in the settling or partial agglomeration of the large and small grains of the unsifted sand, thus diminishing the delivery of water to one-half, one-third, and ultimately to one-fifth of its previous volume. This led to the adoption of sand the grains of which were uniform in size, and to the discovery of the fact that, other things being equal, the resistance to filtration is constant when the sand is coarse, when the grains of fine sand are nearly of equal size, and when there is but little fine sand mixed with the coarse. From experiments in filtering through a layer of coarse sand, approximately 4 inches (10 centimètres) thick, it was found that the higher the temperature, the more rapid was the delivery; and by filtering through a layer of coarse sand, 11·8 inches (30 centimètres) thick, the conclusion was arrived at that the temperature exerts an influence in proportion to the thickness of the layer. The Author then demonstrates the general law for all thicknesses of coarse sand,

$$V = 2{\cdot}5\,E + (0{\cdot}4 + 0{\cdot}06\,E)\,t + \left[1 + \frac{6}{E} + \left(0{\cdot}05 + \frac{0{\cdot}3}{E}\right)t\right] H,$$

when V = speed of water through the filter in millimètres per minute;
E = thickness of the filtering substance in decimètres;
t = temperature in degrees centigrade;
and H = height in decimètres of water above the filtering medium;

and he draws a comparison between the formulæ obtained with layers of coarse sand of different thicknesses at a temperature of 167° Fahr. (75° cent.), and also of 50° Fahr. (10° cent). He compares the delivery of water at the extreme temperature of 32° Fahr. (zero centigrade) and 212° Fahr. (100° cent.), and comes to the conclusion that the delivery at 100° cent. is six times that at zero centigrade.

Sand, the grains of which had a mean diameter of 0·08 millimètre, and which could pass through fine silk, was next used in layers of, approximately, 2 inches (5 centimètres), 4 inches (10 centimètres), 6 inches (15 centimètres), and 7·48 inches (19 centimètres) thick. The experiments and formulæ deduced therefrom lead to the general law for all thicknesses of fine sand,

$$V = (1^{mm} + 0{\cdot}063\,t)\,E + (0{\cdot}5 + \frac{1{\cdot}4}{E} + \frac{0{\cdot}15}{E}\,t)\,H.$$

The record of experiments with a filtering medium, of which sand is the type, is closed by an investigation into the influence on filtration of a mixture of fine sand with coarse, the layer being 15·74 inches (40 centimètres) thick; on account, however, of the filter becoming choked by a greenish mould, at a temperature of 53°·6 Fahr. (12° cent.), it was necessary to use boiling water. The results of these experiments, with the formulæ deduced

from them, are compared with those relating to filtration through fine, and also through coarse sand; and the conclusions are drawn, that the silting-up and fouling of filters by the substances held in solution, or carried along with the water, have the effect of reducing the delivery to one-tenth of the volume which a filter, kept constantly clean, is capable of yielding, and that it is important to have recourse to pressure in order to increase the delivery of filter beds.

In experiments with filamentous filters, wool was taken as a typical substance. The method by which it was compressed is described, and in filtering through layers of, approximately, 4 inches (10 centimètres), 12 inches (30 centimètres), 19·7 inches (50 centimètres), and 15·74 inches (40 centimètres) thick, the results are expressed in the general law —

$$V = 18 + \begin{bmatrix} 0{\cdot}67 \\ \\ +0{\cdot}13\,E \end{bmatrix} t + \left[\begin{pmatrix} 6{\cdot}4 \\ +\dfrac{7{\cdot}6}{E} \end{pmatrix} + \begin{pmatrix} +0{\cdot}17 \\ \dfrac{0{\cdot}15}{E} \end{pmatrix} t \right] H.$$

The effect of compressing layers of wool 8 inches (20 centimètres), 12 inches (30 centimètres), and 19·7 inches (50 centimètres) thick, with the result of the experiments, leads to the theory that compression acts inversely to an increase of temperature, cold being equivalent to compression, while heat may be substituted for the expansion of the layers of a filtering substance. To heat a woollen filter has the same effect as to compress it less, and up to a certain point a woollen filter, very much compressed, acts like a filter of heated sand.

The general laws discovered for speed through the different substances are as follow, p being the pressure, and the other letters retaining their previous values:—

wool,

$$V^{mm} = 16 + 0{\cdot}5\,E + (0{\cdot}59 + 0{\cdot}13\,E)\frac{t}{p} + \\ + \left[6{\cdot}4 + \frac{7{\cdot}6}{E} + \left(0{\cdot}15 + \frac{0{\cdot}21}{E} \right) \frac{t}{p} \right] H$$

coarse sand,

$$V^{mm} = 3 + 1{\cdot}5\,E + (0{\cdot}4 + 0{\cdot}06\,E)\,t + \\ + \left[1 + \frac{6}{E} + \left(0{\cdot}05 + \frac{0{\cdot}3}{E} \right) t \right] H$$

fine sand,

$$V^{mm} = 1\,E + (0 + 0{\cdot}063\,E)\,t + \\ + \left[0{\cdot}5 + \frac{1{\cdot}4}{E} + \left(0 + \frac{0{\cdot}15}{E} \right) t \right] H.$$

The article concludes by giving the delivery of filtered water —per hour and square decimètre of filtering surface, and per

twenty-four hours and square mètre, whence it will be easy to deduce the quantity of water filtered through any surface whatever, and, consequently, to determine the proper area for a filter bed. The three general equations for wool, coarse sand, and fine sand furnish the speed in millimètres, V, of the water descending per minute. This speed, multiplied by 1 square mètre, will give the delivery in litres due to this section each minute, that is to say, $100^{d2} \times 1' \times 0^{d}\cdot01\ V = 1^{d3}\ V = V$ litres. Thus, from the above general equations the speed of the water descending per minute, or the number of litres filtered per minute through 1 square mètre of filtering bed, may be obtained. For instance, when $V = 16^{mm}$, the delivery is 16 litres per minute through each square mètre of filtering bed. In order to deduce from the preceding formulæ those for the delivery, D^{m3}, filtered per square mètre and per twenty-four hours, the delivery, Q litre per 1^{d2} and per hour, must be multiplied by 24 hours $\times$ 100^{d2} = 2,400 $\times$ 1 litre = $2\cdot4^{m3}$. The delivery, D^{m3}, per 1^{m2} and per twenty-four hours is therefore equal to $2\cdot4^{m3}$ Q. In the same manner the following formulæ are obtained:—

wool (subjected to the pressure p),

$$D^{m3} = 23^{m3}\cdot04 + 0^{m3}\cdot0288\,t + 0^{m3}\cdot86\,\frac{t}{p} + \\ + \left[0^{m3}\cdot72 + 0\cdot1872\,\frac{t}{p}\right] E + \left[9^{m3}\cdot17 + 0\cdot216\,\frac{t}{p} + \left(\frac{10^{m3}\cdot944 + 0\cdot3024\,\frac{t}{p}}{E}\right)\right] H$$

coarse sand (0·15 millimètre),

$$D^{m3} = 4^{m3} + 0\cdot576\,t + \\ + \left[2^{m3}\cdot16 + 0\cdot0864\,t\right] E + \left[1^{m3}\cdot44 + 0\cdot072\,t + \left(\frac{8^{m3}\cdot64 + 0\cdot432\,t}{E}\right)\right] H$$

fine sand (0·08 millimètre), $D^{m3} =$

$$= \left[1^{m3}\cdot44 + 0\cdot090\,t\right] E + \left[0^{m3}\cdot72 + \left(\frac{2^{m3}\cdot016 + 0\cdot217\,t}{E}\right)\right] H$$

fine muddy sand (approximately for actual filtering beds),

$$D^{m3} = \frac{2^{m3}\,H}{E}$$

J. W. P.

Graphic Determination of the Hydraulic Head, velocity of discharge, and time of emptying of fluids from vessels of various forms. By Dr. R. Pröll.

(Civilingenieur, xx. part 5, 1874, cols. 281–294.)

The Author previously published, in the "Civilingenieur" for 1873, a treatise on the Graphic Solution of Dynamic Problems. This was afterwards issued as a separate work. The present Paper contains an application of the Author's methods to some problems in hydrodynamics. Consider a conveniently formed vessel filled to a known height with a fluid. The vessel has in its lower end an orifice through which the fluid is discharged. Then at any moment when the depth of fluid over the orifice is h, the velocity of discharge is $v = \sqrt{2\,g\,h}$, the resistances being for the present neglected. If vertical and horizontal axes are taken, a curve can be drawn, the horizontal abscissæ of which at each point are proportional to the velocity of discharge when the water is at the corresponding level in the vessel. In this case the curve, which may be obtained by known methods, is a parabola whose parameter is g. The Author next draws a curve, the abscissæ of which represent the rate of sinking of the water surface. If f is the area of the orifice, and F the area of the section of the vessel at a height h above the orifice, and if v is the velocity of discharge, and w the velocity of sinking of the water surface, then $w = v\,\frac{f}{F}$, or, in other words, w can be obtained from the abscissæ of the previous curve by reducing it in the ratio f: F. From the nature of the curve, it is only necessary to make this construction for a few points, and to draw a line freely through the points so found.

The Author next supposes a point in a third curve, termed the time curve, to move with a uniform velocity u, in such a way that it remains always in the plane of the water surface; the length of the arc between any two points is then proportional to the time which elapsed while the water sunk from the level of the first to the level of the second. The method of drawing this had been previously given by means of the second curve above mentioned. When this has been done, all problems relating to the time of discharge can be solved by measuring the time curve. If l is the length of the arc between any two levels of the water surface, the time

$$t = \frac{l}{u}.$$

The Author next shows how from the two curves first drawn, the hydraulic heads at different depths in the vessel can be found graphically as linear magnitudes. He explains how this method may be applied to the case where the pressure on the surface of the fluid (constant or variable) is different from the pressure outside the orifice of discharge, and how to take into the reckoning

the resistance at the mouthpiece and the contraction of the jet. After discussing the scales suitable for drawing the different curves, and showing how to allow for the difference of scale, in measuring the results, he ends by giving examples of the application of the method to particular cases.

W. C. U.

Rainfall of the Basin of the Seine. By M. Belgrand.

(Comptes-rendus de l'Académie, lxxviii., March 30, 1874, pp. 870–878.)

This Paper is a continuation of the hydrologic studies pursued by MM. Belgrand and Lemoine during twenty years, the results of which were published by them, under the title of "La Seine, Etudes Hydrologiques," in 1872. That year was remarkably dry at the commencement and very wet in the autumn, and the observations taken during those seasons verified the law enunciated in 1854, that the climate of France is uniform to the north of the central plateau, particularly in the basin of the Seine; for, at the same dates, the rainfall was everywhere similar. It was observed that the altitudes of places, and their distances from the sea, greatly modified the rainfall—for instance, "Le Haut Follin," the highest point of the Yonne, has also the greatest rainfall; the altitude being 2,959 feet (902 mètres), and the rainfall in 1872 as much as 105·55 inches (2,681 millimètres). Four[1] neighbouring stations, "Le Bas Follin," "Pommoy," "Croisette," and "Settons," whose heights are 2,625 feet (800 mètres), 2,133 feet (650 mètres), and 2,139 feet (596 mètres), had generally decreasing rainfalls of 96·7 inches (2,457 millimètres), 99·7 inches (2,533 millimètres), 83·5 inches (2,121 millimètres), and 80·3 inches (2,041 millimètres) respectively. At the lowest station of the Yonne, "St. Martin," at 217 feet (66 mètres), the rainfall was 30·9 inches (787 millimètres), the ratio of the highest to the lowest being as 2,681 to 787, or as 3·4 to 1.

The stations situated beyond 93 miles (150 kilomètres) from the sea receive the smallest amount of rain. Only 22·63 inches (575 millimètres) descended at the lowest point, "Port d'Anglais," at an elevation of 108 feet (33 mètres). The effect of proximity to the sea, on the other hand, is shown by the rainfall at various points, which approaches that of mountainous districts, viz.:—

Stations:—		Gournay.	Rouen.	Caudebec.	Yvetot.	Havre-Ingouville.
Height	in feet	328	26	3·28	495	292
	in mètres	(100)	(8)	(1)	(151)	(89)
Rainfall	in inches	33·31	33·39	40·71	47·7	42·6
	in millimètres	(846)	(848)	(1,034)	(1,212)	(1,083)

[1] Although four stations are spoken of, the altitudes of three alone are given in the original.—Sec. Inst. C.E.

A station at the bottom of a valley near a more elevated plateau receives almost as much rain as that plateau—Settons, at 1,955 feet (596 mètres), is as wet a place as neighbouring stations at 2,959, 2,625, and 2,133 feet (902, 800, and 650 mètres); the rainfall exceeding in 1872 78·74 inches (2,000 millimètres). At stations which are not in the vicinity of these heights the rainfall is considerably less; for instance, at Saulieu and Château-Chinon, 1,827 feet (557 mètres) and 1,768 feet (539 mètres) respectively, though nearly the altitude of Settons, it amounted only to 37·79 inches (960 millimètres) and 50 inches (1,271 millimètres).

The number of rainy days near the sea is much greater than at any other part of the basin; in 1872 there were at Yvetot 223, at Caudebec 200, at Fatouville 207, while the mean number for the entire basin does not exceed 164. The mean rainfall over the entire basin in 1872 was 34·65 inches (880 millimètres); the average for eight years being 27·87 inches (708 millimètres). The mean results from observations over the great river-basins during 1872 were—

	Inches.	MM.		Inches.	MM.
Basin of the Yonne	47·166	(1,198)	Basin of the Marne	40·395	(1,026)
,, Upper Seine	36·103	(917)	,, Aisne.	33·623	(854)
,, Middle Seine	28·937	(735)	,, Oise .	30·552	(776)
,, Loing.	30·119	(765)	,, Beauce	31·969	(812)
			,, Lower Seine	35·749	(908)

The Paper also describes the tranquil and torrential streams of the Seine basin, and the peculiarities of their different floods.

L. G.

The Hydrology of the Basin of the Seine. By M. A. Delaire.

(Annales du Conservatoire des Arts et Métiers, No. 138, 1874, pp. 335–392.)

The entire basin of the Seine is subject to similar meteorological influences, and, though the amount of rain varies with the locality, yet the season, whether wet or dry, is of the same character along the whole extent of the basin, as proved both by rainfall observations, and by the height or lowness of the streams. The winter rainfall determines the moisture of the soil throughout the year, as the summer rains produce little effect on the rivers or springs. The sources and the nature of the rivers vary according to the geological character of the district; thus where the soil is impermeable—as, for instance, the granite of Morvan, the lias of Auxois, and the clay of Champagne—the streams are numerous but small, and, as the water runs quickly off the surface, the streams and rivers swell rapidly, in time of rain, forming torrents, the beds of which are generally dry in summer. In permeable soils, such as the öolitic limestone of Bourgogne, the white chalk of Normandy, and the sands of Fontainebleau, the streams rise in

the marshy meadows of deep valleys, the springs are considerable, and are frequently found at the junction of permeable with impermeable strata; the rivers are few, not generally liable to dry up, and their course is gentle. The impermeable soils occupy 7,722 square miles (20,000 k. q.) out of the total area of 30,501 square miles (79,000 k. q.) of the Seine basin.

The torrential rivers have frequent, high, and rapidly rising floods; the rivers flowing through permeable strata rise slowly, and only swell moderately; but, owing to successive rainfalls being merged together, they continue in a state of flood for a long period, and consequently are more injurious to the adjacent lands. Some rivers fed by torrential and other tributaries occupy an intermediate position, and their highest floods occur when a torrential flood follows several other successive risings. The torrential floods flow through Paris at the end of three or four days, and the other flood waters follow three or four days later. An ordinary rise of flood at Paris is about 11½ feet (3·5 mètres), and a rise of 23 feet (7 mètres) has only occurred eight times since 1649; extraordinary floods being the result of a thaw followed by excessive rain.

The bridges over a torrential river have to be larger and more numerous than those over rivers flowing through permeable strata, but their span need not be increased proportionately at the lower points of the river, as the flood from one torrent subsides before another from higher up arrives; whereas floods in rivers flowing through permeable or mixed strata are increased by each affluent. In most parts of the basin the rivers have a navigable depth of water of 4 feet 11 inches (1·5 mètre), but the locks vary from 108 to 590 feet (33 to 180 mètres) in length, and from 16 to 39 feet (5 to 12 mètres) in width. The torrential rivers are of little use as water power, their flow being irregular, but for agricultural purposes, and for supplying canals, the flood waters are led into large ponds to provide against the summer drought. For mill-dams across rivers flowing over impermeable strata large weirs and no sluices are required; over slightly permeable strata both weirs and sluices, and over permeable strata sluices only, are necessary.

Water for domestic use is obtained purer from springs than from rivers, even though containing in general more salts of lime. The purest sources are in sandy soils, and the hardest water comes from the limestones, lias, and gypsiferous strata. The water supply of Paris is obtained from the Dhuis and the Vanne.

L. V. H.

Flow of the West Branch of the Croton River.

By J. James R. Croes.

(Transactions of the American Society of Civil Engineers, July 1874, pp. 76–86, 2 pl.)

The first storage reservoir for impounding a portion of the surplus flow of the river, begun in 1866, on the western branch of the Croton, in the town of Kent, 60 miles north of New York, receives the drainage of 20·37 square miles; the surface of the watershed being broken, the hillsides steep and rocky, the area covered with timber and grass, and the rock underlying the area a compact gneiss. Two thousand five hundred and ten observations of the flow of the stream were made near the dam, from April 1867 to November 1872, during certain periods as often as three times a day. All the water flowing from the drainage area to the reservoir was caused to pass over a weir with a horizontal crest, and provided with vertical side boards 1 inch thick. In the first series of gaugings the weir was 24 feet long, in subsequent ones 21·15 feet, afterwards reduced to 18·02 feet. The channel just above the weir was 3 feet wider than the weir was long, with parallel sides, planked for 15 feet, above which it widened. The height of the crest of the weir above the bottom of the channel on the upper side was about 18 inches, and there was a clear fall of about 30 inches on the lower side. With this weir and heads of water of 0·15 foot to 4 feet perfect contraction was obtained. The head was measured by a float gauge inclosed in a box, and attached to a graduated rod. Ordinarily there was no difficulty in reading this gauge to 0·005 foot. When the float was unsteady, the mean of the oscillations for several minutes was taken. The gauge was placed far enough above the weir to be unaffected by the slope of the surface of the water in passing over the weir. In gaugings later than 1868, the channel was obstructed by a dam with two openings of 4½-feet diameter.

In storms the flow increased as soon as the rain began to fall, the maximum being reached six to eight hours after the rain had ceased. On the 1st of August, 1867, the flow was 28,000 cubic feet per hour. Between 7 P.M. and noon next day 1·96 inch of rain fell, and by 6 P.M. the volume had increased to 336,000 feet per hour. On the 15th, rain having fallen in the interval, the flow at 7 P.M. was 242,000 cubic feet per hour. At 10 A.M. of the 16th 3·38 inches of rain had fallen, and by 6 P.M. the flow had reached 2,432,000 cubic feet, an average hourly increase of 95,000 cubic feet. This was the greatest discharge observed. On the 17th of February, 1870, the ground being covered with snow, thaw set in, with 2·41 inches of rain in twenty-eight hours. The water came in such quantities that the openings in the dam were insufficient to carry it off; it rose 20 feet, nearly 50,000,000 cubic feet having accumulated behind the dam. For twenty-four hours the flow was 2,200,000 cubic feet per hour, making 52,800,000 cubic feet per day;

the maximum discharge must have been about 3,500,000 cubic feet per hour; while during the month of September 1870 the total discharge of the stream for thirty days was only 4,508,000 cubic feet. Accompanying diagrams show the monthly rainfall from June 1866 to January 1874, and the flow of the stream during the forty-nine months in which gaugings were made; a set of tables gives the depth of rainfall on the entire watershed, the ratio of flow to rainfall, the yearly proportion of flow to rainfall, and comparisons of different gaugings.

J. D. L.

Relation between Water Levels of Main Rivers in Holland.

By J. P. Delprat.

(Tijdschrift van het Koninklijk Instituut Van Ingenieurs, No. 1, 1874, pp. 1–12.)

The purpose of this investigation is to find a simple formula from which the height of the water level at any point of a river may be deduced, when the height at any other station along the same river is known by observation during two consecutive days.

Supposing the increase and decrease in height of water level along the river to be changing in the same ratio, the formula becomes:—

$$H = a + bh + ch^1, \text{ where}$$

a, b, and c denote constant co-efficients, which depend upon the form of the river bed, and the distance from each place to the station, taken as the basis of the calculations and observations;

h and h^1 represent the height of the water line during two consecutive days at the main station;

H the same height on the latter of the two days at any other point along the river.

The constant co-efficients are to be deduced from a series of observations. In Holland these observations are made daily with regard to the height of the water along the main rivers, at distances varying from 4 to 30 kilomètres. The correctness of the formula is checked by comparing the results of the calculations with the observations at an earlier or a later date than those chosen for the basis. The Author has calculated the value of a, b, and c for several places along the two main branches of the Rhine, called the Waal and the Neder-Rhijn, or Lek, where observations showed a considerable rise and fall of water during a short time. When applying the formula to cases of an earlier or a later date, and comparing the results with those already obtained, the differences were found to be very small, seldom amounting to a décimètre. As soon as the rivers get into an abnormal state—for instance, in consequence of the breaking or overflowing of a dam—the formulæ are no longer applicable; the differences between

observation and calculation amounting in some cases to 50 or 70 centimètres.

Here the formula indicates the influence of accidents upon the height of the water. If, for instance, the heights at the main station and at any other be observed, the height for the latter is deduced from the formula, the result giving the height of water under normal circumstances; nearly the whole variation therefore is to be considered the consequence of the abnormal conditions. Several examples and tables prove the correctness of the formula, and its practical value. J. M. T.

Observations on Subterranean Water in Dresden.

By Herr Manck.

(Protokolle des Sächsischen Ingenieur-Vereins, Sept. 7, 1874, pp. 4–9.)

It having been asserted by the Munich physician Von Pettenkofer that the lowness of subterranean water was distinctly connected with outbreaks of epidemics, observations of subterranean watercourses were commenced in Dresden in 1867, and have been continued down to the present day, at ninety-two wells selected in various parts of the old town, the new town, and the suburbs. Eighteen principal wells were examined every Monday morning at six o'clock, and the other seventy-four on the first of every month; the operations being under the immediate direction of the Author. As a measuring instrument he employed an impervious tape with a slate stave attached to the end. The relation between the surface of each well and the level of the Elbe being exactly known, a simple calculation was sufficient to determine the height of the subterranean water-level above that level. The heights thus ascertained varied considerably; on the left bank of the river between 13·1 feet and 72·2 feet (4 mètres and 22 mètres); on the right bank between 16·4 feet and 59 feet (5 mètres and 18 mètres), the difference being partly caused by the variation in the surface, partly by the impervious layers of stone on which the water moved. These layers consisted principally of ragstone at a depth of from 39·4 feet to 54 feet (12 to 16·5 mètres) below the surface; the upper strata being on the left bank coarse gravel and pebbles, and on the right bank fine gravel and sand. It was found that in the strata of coarse gravel and pebbles the variations in the water level were much more pronounced and sudden. By means of horizontal curves drawn on the plan of the city to represent the simultaneous observations, and by lines connecting different wells, the Author was enabled to calculate with tolerable accuracy the rapidity with which the water travelled from one pump to another, and having taken a line running from three such wells to the Elbe, he found that in thirty-five days the water percolated from the Königsbrücker well

to the river. Chemical analysis proved the presence of nitrites and nitrates, indicating contamination from cesspools and drains. The old town surrounded by the ancient walls has generally very bad water, the suburbs, on the other hand, mostly good water, except where it has been spoiled by the products of the tanning yards. By these observations it has been possible to localise contamination, and point with precision to its source; for whereas in some parts of the suburbs the water is very impure, the pumps on the Trinity churchyard and the Jewish churchyard contained perfectly pure water, the level there being low, and the soil exceedingly fine. The fact that, in the midst of the old city, pumps supply water free from nitrates, shows that the great mass flowing continually towards the river is pure, and can be made purer.

J. D. L.

On the Flow of Atmospheric Air. By Albert Fliegner.

Prof. of Theoretical Mechanics at the Federal Polytechnic School in Zurich.

(Civil-Ingenieur, xx., part 1, 1874, cols. 14–47.)

Let atmospheric air flow from a vessel, in which the pressure, specific volume and temperature have the constant values p_2, v_2, t_2, into another vessel in which the pressure is constant and equal to p_1, through an opening of area F. Then the velocity w of discharge and the weight G discharged per second, on the hypothesis that the air neither receives nor parts with heat, are given by the expressions:—

$$w = \sqrt{\left\{2g\,\frac{k}{k-1}\,(p_2 v_2 - p_1 v_1)\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

$$G = F\sqrt{\left\{2g\,\frac{k}{k-1}\,\frac{p_2}{v_2}\left[\left(\frac{p_1}{p_2}\right)^{\frac{2}{k}} - \left(\frac{p_1}{p_2}\right)^{\frac{k+1}{k}}\right]\right\}} \quad . \quad . \quad . \quad . \quad (2.)$$

These formulæ neglect the resistances, which Zeuner was the first to take into account. He changed equation 2, by putting for the exponent of the adiabatic curve, $k = 1{\cdot}41$, in the expression in angular brackets, a discharge exponent $n < k$. Then

$$G = F\sqrt{\left\{2g\,\frac{k}{k-1}\,\frac{p_2}{v_2}\left[\left(\frac{p_1}{p_2}\right)^{\frac{2}{n}} - \left(\frac{p_1}{p_2}\right)^{\frac{n+1}{n}}\right]\right\}} \quad . \quad . \quad . \quad . \quad (3.)$$

Also, $$p_2 v_2^{\,n} = p_1 v_1^{\,n}.$$

When the inner pressure is constant and the external pressure varies, both (2) and (3) give a maximum value of G for a given ratio of p_1 to p_2, a result neither probable nor agreeing with experience. To render the formulæ useful a correction must be applied.

Two proceedings may be followed. The actual mouthpiece area F may be replaced by a peculiar contraction, area a F $<$ F, and the co-efficient a found by experiment. Or the path taken may be that indicated first by St. Venant and Wantzel, and later, independently, by J. R. Napier, and adopted by Zeuner and Rankine. Equations (1) to (3) are indisputable if p_1 be the pressure in the plane of the mouthpiece. The peculiar deduction from the formulæ would therefore indicate that the pressure in the plane of the mouthpiece is not always equal to the external pressure. In his approximate formulæ, Napier assumed that for $p_1 > 0{\cdot}5\ p_2$ the external pressure extends to the plane of the mouthpiece; for $p_1 < 0{\cdot}5\ p_2$, on the contrary, the pressure in the plane of the mouthpiece is independent of the external pressure, and remains constantly $= 0{\cdot}5\ p_2$. The limiting value $\frac{p_1}{p_2} = 0{\cdot}5$ corresponds to the maximum value of G in Napier's approximate formulæ. The accurate equation (2) gives the value 0·5266, and if the resistances are taken into account it would be greater.

Napier tested his formulæ by experiments with steam. The Author indicates some defects in the method of these experiments, and since a discontinuity of the above description is very improbable, at all events for air, concludes that Napier's results are only approximate. The question as to the pressure in the mouthpiece plane being of fundamental importance, it is desirable to have direct experiments on that point.

In these experiments the same apparatus was used which Zeuner had employed. Well-rounded mouthpieces only were subjected to experiment, having a narrow cylindrical part at the outer end, to prevent contraction of the jet. Into this cylindrical part opened a small orifice ·04 in. (1^{mm}) in diameter, communicating with a manometer. The pressure in the interior of the reservoir was indicated by an air manometer. The experiments were made as follows:— The cock was opened for about a minute. During the flow, the manometers were read about every five seconds, simultaneously, by word of command. The person giving the signals caused these moments of time, and also those of opening and of closing the cock, to be registered by the seconds finger of a chronometer with the aid of electricity. When the temperature in the reservoir was again equal to the external temperature the experiment was continued. Sometimes the discharge was allowed to take place for a shorter time, and the pressures at opening and closing the cock were alone noted. The results thus obtained were less accordant.

The Author indicates some difficulties and sources of error in this method. Reliable numerical results were obtained with only two mouthpieces. The diameter of one was 0·16 in. ($4{\cdot}085^{mm}$), that of the other was 0·29 in. ($7{\cdot}314^{mm}$). Tables of experiments with these mouthpieces are given, and the results are also exhibited graphically. Let p' be the pressure in the plane of the mouthpiece and p_2 that in the reservoir. By setting off the observed values of

p_2 horizontally and those of p' vertically, and by connecting the points thus given, a curve is obtained. This curve commences at the point whose ordinate and abscissa are both equal to the barometric pressure during the experiment, because for that point the external and internal pressures, and the pressure in the plane of the mouthpiece, are all equal. The external pressure remaining constant, and the internal pressure increasing, the curve representing the corresponding values of p' follows approximately an inclined straight line. When the inner pressure is about twice the external pressure, the curve rises with a sharp bend, in order to approach asymptotically a straight line, passing through the origin of co-ordinates. The curve approaches its asymptote so rapidly, that when the inner pressure is a little more than twice the external pressure, it may be replaced by the asymptote without any great error. The direction of the asymptote the Author supposes to be independent of the external pressure. The mean value $\frac{p'}{p_2}$, which determines this direction, is found from the experiments to be

$$\frac{p'}{p_2} = 0{\cdot}5767 \quad . \quad . \quad . \quad . \quad (4.)$$

These results show Napier's hypothesis to be inaccurate, but it may be accepted as the simplest approximation to the true law.

The hypothesis mentioned above also assumes that the ratio $p_1 : p_2$, or more strictly $p' : p_2$, can never be smaller than that value of it which makes the expression in equation (3)

$$\psi = \left(\frac{p_1}{p_2}\right)^{\frac{2}{n}} - \left(\frac{p_1}{p_2}\right)^{\frac{n+1}{n}} \quad . \quad . \quad (5.)$$

a maximum. The Author shows that this leads to the result, that the co-efficient of resistance of the mouthpiece has the enormous value $\zeta = 1{\cdot}4$, while for water it is only 0·063. He concludes, therefore, that the limiting value to which the ratio $\frac{p'}{p_2}$ approximates asymptotically is not related to the maximum of ψ, but is dependent on other circumstances. Further, he rejects the hypothesis that the maximum velocity of discharge is equal to the velocity of transmission of sound.

A totally different limiting value for the velocity of discharge can be obtained from the theory of the molecular constitution of permanent gases. According to that theory the molecules are at relatively great mean distances from each other. They move in straight lines till they impinge on other molecules, or on a solid boundary. Then they rebound as iffrom perfectly elastic impact. The pressure p of the gases against a solid boundary (in kilos. per sq. mètre) [lbs. per sq. ft.] is due to this impact, and depends on

the mass M contained in 1 cub. mètre and the mean constant velocity u of the molecules. It is given by the expression

$$p = \tfrac{1}{3}\,\mathrm{M}\,u^2 \text{ or } \mathrm{M}\left(\frac{u}{\sqrt{3}}\right)^2;$$

that is, it is equal to the *vis viva* of the whole mass impinging against the boundary with the velocity $u : \sqrt{3}$. If the boundary is immovable the mass rebounds with the same velocity. If, on the contrary, the boundary is displaced, in consequence of the smaller external pressure, the particles rebound with less velocity than they approached. Proceeding to the limit, and assuming the external pressure to be equal to zero, then the impinging mass will not be impeded, but will proceed with its velocity

$$w = \frac{u}{\sqrt{3}}$$

unchanged, and this must be the greatest velocity of discharge. The limiting value of p' must therefore be so assumed that w does not exceed this value.

Let v be the specific volume of air at the temperature T

$$\mathrm{M} = \frac{1}{g\,v}$$

$$\therefore p = \frac{u^2}{3\,g\,v},$$

and since for permanent gases

$$p\,v = \mathrm{R\,T},$$

$$w_{\max.} = \frac{u}{\sqrt{3}} = \sqrt{g\,\mathrm{R\,T}},$$

inserting the known values of the constant, and replacing T by the temperature of the reservoir

$$w_{\max.} = 16{\cdot}946\,\sqrt{\mathrm{T}_2} \quad . \quad . \quad . \quad . \quad (7.)$$

$$[w_{\max.} = 55{\cdot}605\,\sqrt{\mathrm{T}_2}].$$

It is also possible to obtain w as a function of T_2 from equation (1). Put $p_2\,v_2 = \mathrm{R\,T}_2$ and neglecting the resistances

$$p_2\,{v_2}^k = p_1\,{v_1}^k.$$

After reduction

$$w = \sqrt{\left\{2\,g\,\frac{k}{k-1}\,\mathrm{R\,T}_2\left[1 - \left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}}\right]\right\}}.$$

For the limiting value found by experiment, namely

$$\frac{p_1}{p_2} = \frac{p'}{p_2} = 0{\cdot}5767,$$

this gives

$$w_{\max.} = 17{\cdot}092\sqrt{T_2} \quad . \quad . \quad . \quad . \quad (8.)$$
$$[w_{\max.} = 56{\cdot}077\sqrt{T_2}].$$

This value agrees so closely with that in (7) that the Author assumes his hypothesis as to the limiting velocity to be correct.

When the law of the change of pressure in the plane of the mouthpiece has been approximately obtained by experiment, the exponent of discharge n in equation (3) can be determined by other experiments. But as n can only be found by trial, in consequence of the form of the equation, the Author prefers to make an hypothesis as to the value of n, and to test it afterwards by experiment.

Theoretical considerations show that as the co-efficient of resistance for water flowing through thin-edged orifices is the same as that for well-rounded mouthpieces, the resistance must be chiefly internal, and the external frictional resistance against the mouthpiece sensibly zero. But for air the internal resistance is also zero. Hence for air there is no sensible resistance, at thin-edged orifices or well-rounded mouthpieces, and consequently $n = k$. If this is true, then eq. (2) gives the discharge, when the pressure p_1 is understood to mean the pressure p' in the plane of the mouthpiece. This equation can be put in a more convenient form. For permanent gases $p_2 v_2 = \mathrm{R}\,\mathrm{T}_2$. For simplicity also let

$$\psi = \left(\frac{p'}{p_2}\right)^{\frac{2}{k}} - \left(\frac{p'}{p_2}\right)^{\frac{k+1}{k}} \quad . \quad . \quad . \quad . \quad (9.)$$

Then equation (2) becomes

$$\frac{\mathrm{G}}{\mathrm{F}} = p_2 \sqrt{\left\{\frac{2g}{\mathrm{R}} \cdot \frac{k}{k-1} \cdot \frac{\psi}{\mathrm{T}_2}\right\}} \quad . \quad . \quad . \quad . \quad (10.)$$

When the internal pressure p_2 is more than about double the external barometric pressure b, the pressure in the plane of the mouthpiece has been shown to be independent of the external pressure. In that case $p' : p_2$, and consequently ψ is constant. It follows that

$$\frac{\mathrm{G}}{\mathrm{F}} = m p_2 \quad . \quad . \quad . \quad . \quad (11.)$$

m depending only on the temperature and having the value for $p' : p_2 = 0{\cdot}5767$

$$m = \frac{5{\cdot}3728}{\sqrt{\mathrm{T}_2}} \quad . \quad . \quad . \quad . \quad (12.)$$

[for lbs. per sq. ft. and pressure in inches of mercury $m = \dfrac{27{\cdot}95}{\sqrt{\mathrm{T}_2}}$

For smaller internal pressures, the Author finds the following em-

pirical expression to agree almost exactly with experiment, the values of $\frac{G}{F}$ having been calculated by equation (10) from the experimentally ascertained values of p'

$$\frac{G}{F} = \sqrt{a\,(p_2 - b)} \quad . \quad . \quad . \quad . \quad (13.)$$

and the value of a is found to be such that this expression is almost exactly equal to

$$\frac{G}{F} = 2\,m\,p_2\,\sqrt{(p_2 - b)},$$

a being dependent on the temperature and internal pressure, and m having the same value as before.

These expressions, obtained on the hypothesis that for well-rounded mouthpieces the resistance is insensibly small, require next to be tested by experiment. The Author discusses fully the difficulties and sources of error to which experiments on the flow of air are liable.

Tables of experiments by Zeuner, Weisbach, and the Author are then given, and the values of a and m are calculated from them. If the hypothesis that $k = n$ is true, these values should agree with the independent values given above. This is found to be the case.

W. C. U.

Results of Experimental Researches on the Discharge of Air under Great Pressures. By Dr. Gustav Zeuner.

(Civilingenieur, xx., part 1, 1874, cols. 1–14.)

These researches on the flow of air through simple mouthpieces were made with a large apparatus belonging to the Federal Polytechnic School at Zurich. The Author gives a short history of the question for solution, to explain the necessity for the experiments. If air flows from one vessel in which the pressure is constant into another in which the pressure is also constant, the air expands during its flow from the mouthpiece in consequence of the difference of pressure which must be gradual between the two limits. According to the assumptions made, as to the law connecting the change of pressure and volume of the moving air, different formulæ of discharge are obtained. Let p_2 be the pressure in the reservoir, from which the air is discharged (in kilogrammes per square mètre, lbs. per square foot), and p_1 that in the receiving vessel. Then, assuming the temperature of the air to remain constant, the formula of Navier (1827) is obtained, which gives for the velocity of discharge

$$w = \sqrt{\left\{2\,g\,R\,T_2 \log\,p_2\right\}} \quad . \quad . \quad . \quad (1.)$$

and for the volume discharged V, measured at the inner pressure, per second and per square mètre (square foot) of mouthpiece area,—

$$V = \frac{p_1}{p_2} \sqrt{\left\{2\,g\,R\,T_2 \log \frac{p_2}{p_1}\right\}} \quad . \quad . \quad . \quad (I.)$$

where R has a constant value, and for air and for metric measures, is equal to 96·012 feet (29·272 mètres); g is the acceleration of gravity, and T_2 the absolute temperature of the air in the reservoir on the centigrade scale.

If, on the contrary, it be assumed that the air flowing through the mouthpiece expands in an adiabatic curve—that is, without receiving or losing heat—then the formula of Weisbach (1855) is obtained, giving for the velocity of discharge

$$w = \sqrt{\left\{2\,g\,\frac{k}{k-1}\,R\,T_2\left[1-\left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}}\right]\right\}} \quad . \quad . \quad (2.)$$

in which k is a constant, which for air is 1·41. The volume discharged is—

$$V = \sqrt{\left\{2\,g\,\frac{k}{k-1}\,R\,T_2\left[\left(\frac{p_1}{p_2}\right)^{\frac{2}{k}}-\left(\frac{p_1}{p_2}\right)^{\frac{k+1}{k}}\right]\right\}} \quad . \quad . \quad (II.)$$

The preceding formulæ had been given in 1839 by St. Venant and Wantzel. If the resistances be taken into account, the right-hand member of equation (II.) must be multiplied by a factor of correction, the co-efficient of discharge. Or, the investigation may proceed on the supposition that the resistances merely change the expansion curve. From theoretical considerations the Author was thus led to the following formulæ :—

$$w = \sqrt{\left\{2\,g\,\frac{k}{k-1}\,R\,T_2\left[1-\left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}}\right]\right\}} \quad . \quad . \quad . \quad (3.)$$

$$V = \sqrt{\left\{2\,g\,\frac{k}{k-1}\,R\,T_2\left[\left(\frac{p_1}{p_2}\right)^{\frac{2}{n}}-\left(\frac{p_1}{p_2}\right)^{\frac{n+1}{n}}\right]\right\}} \quad . \quad . \quad (III.)$$

in which n is a constant to be determined by experiment, is smaller than k, and may be termed the exponent of discharge.

A consideration of these formulæ leads to the question requiring solution. If the inner pressure p_2 and the inner temperature T_2 be invariable, and for different experiments different external pressures p_1 be taken, then all three formulæ indicate that an external pressure exists, for which the discharge per second and per unit of mouthpiece area is a maximum. The values of the ratio $\frac{p_1}{p_2}$ which make V a maximum are then calculated, and are shown to lie for all the formulæ between 0·5 and 0·6. Now, if the discharge is a maximum when the external pressure is

about half the internal pressure, it follows that the discharge diminishes if the external pressure is further diminished, and the formulæ show that it becomes zero simultaneously with the external pressure. Accordingly, into a vacuum there is no discharge. It follows from this absurd result, either that all the formulæ are false, or that in using them some inadmissible assumption has been made. It is now believed that the latter is the case, and St. Venant and Wantzel, in 1839, pointed out that the pressure p_1 is not the pressure in the receiving vessel, but in the plane of the orifice, and that these two pressures are only identical when $p_1 : p_2$ is greater than about 0·4. They supposed that when the ratio is smaller, the discharge remains constant, and also $p_1 : p_2$, if by p_1 is understood the pressure in the plane of the mouthpiece. The ratio 0·4 was obtained from their experiments, to test the accuracy of the preceding hypothesis.

The work of St. Venant and Wantzel remained a long time unnoticed, owing chiefly to Poncelet having raised the objection that the scale of their experiments was too small. Max Hermann first returned to the question (1860) after Weisbach (1855) had rediscovered equation (II.). In 1871, Rankine investigated the question, reopened by Napier's experiments on a large scale on the flow of steam, and the Author then published his formula (III.). Considerations drawn from the mechanical theory of heat led to the conclusion that St. Venant and Wantzel's method of investigation was faulty, and other experiments did not furnish the data requisite for a solution of the question, because the pressures at which they were made were not sufficiently great.

The Author had for several years been convinced of the accuracy of the hypothesis of St. Venant and Wantzel, and felt the desirability of subjecting it to larger and more careful tests. His apparatus consisted of a cylindrical vessel of boiler plate, 13·78 feet (4·2 mètres) in length, and 1·64 foot (0·5 mètre) in diameter. Its capacity, gauged with great care, was 28·637 cubic feet (0·81088 cubic mètre). The vessel was proved to ten atmospheres, and was furnished with a pump, by which air could be compressed into it. It carried a seating with a wide neck, having a tight cock with a wide passage through it, on the open end of which the mouthpiece could be fitted. A well-divided open mercury manometer was connected with the interior of the reservoir, and was capable of indicating pressures up to four atmospheres. The apparatus was similar to that of Weisbach, and the Author at first supposed that a simple extension of Weisbach's experiments to higher pressures would suffice to solve the question at issue. A series of experiments soon showed that a circumstance had to be taken into account, which had been overlooked, and which greatly affected the results. In Weisbach's method, after the air has been compressed, and the equilibrium of temperature re-established, the pressure in the reservoir is noted. The air is next allowed to flow for one or two minutes into the receiver, when the cock is quickly closed, and the height of the manometer observed.

After the mercury gauge has again become stationary, its height is again noted. During the discharge there is a fall of temperature in the reservoir. After closing the cock, heat enters through the sides of the reservoir, and the pressure rises, until, the temperature inside and outside having become equal, it again becomes constant. The three pressure observations suffice to test the accuracy of the formulæ of discharge, if the temperature and barometric pressure of the external air and the capacity of the reservoir are known. But they are not sufficient, unless, as Weisbach assumed, the air in the boiler expands without receiving or losing heat. During the relatively long period of discharge the pressure change in the reservoir followed a different law, in consequence of the heat imparted to it during expansion by the sides of the reservoir. The Author therefore adopted a new method of experiment. He permitted the air to flow, at intervals, in the following way. After the air in the reservoir was compressed to about four atmospheres, and the manometer showed the equilibrium of temperature to be established, the cock was opened, and the air allowed to flow for about ten seconds. At the end of the time the cock was closed, and the manometer level noted. After about ten or fifteen minutes the manometer was again noted. The experiments were thus continued till the pressure in the reservoir was reduced nearly to that of the external air. From the short duration of each experiment, the influence of the heat given to the air by the reservoir sides was so much diminished that it could be allowed for by a simple formula of approximation.

For any single experiment, let the initial pressure in millimètres of mercury column $= h_2$; the final pressure, after closing the mouthpiece and after the equilibrium of temperature is re-established, $= h_1$, and the time of discharge $= t$. Then for a first approximation

$$\frac{1}{t} \log \frac{h_2}{h_1}$$

should be constant, so long as the inner pressure is more than about twice the external pressure, if the above hypothesis be true. On the other hand, the value of this expression must diminish with the inner pressure as soon as it becomes less than about double the external pressure.

The Author experimented with three kinds of mouthpieces: 1. Short, internally rounded conoidal mouthpieces, of 0·161, 0·228, 0·276 inch (4·1, 5·78, and 7·0 mm.) diameter. 2. Short cylindrical mouthpieces, with the internal edges not rounded, of 0·228, 0·276 inch (5·79 and 7·0 mm.) diameter. 3. Orifices in thin plates of 0·161, 0·228, 0·276, 0·394 inch (4·09, 5·79, 7·0, and 10·0 mm.) diameter.

The first two kinds of mouthpieces gave results consistent with the hypothesis of Wantzel and St. Venant. The third kind, orifices in thin plates, showed a small departure from that hypothesis,

which the Author explains by the circumstance that the contraction of the jet alters with the pressure, increasing slowly as the pressure increases.

The defect in the method of experiment employed by St. Venant and Wantzel is then discussed, and one series of experiments is given as a sample of the results obtained.

W. C. U.

The Drainage System of Dantzic.

By Herr von Winter, Mayor of Dantzic.

(Baugewerks Zeitung, Sept. 27, 1874.)

At the last congress of the German Association for Public Health in Dantzic, Herr von Winter, the Mayor, gave a brief account of the drainage system which had been carried out between August 1869 and December 1871. The main sewers are of brickwork in cement, 4 feet 1 inch (4 Fuss) high, 2 feet 9 inches (2 Fuss 8 Zoll) broad, and 13,382 feet (13,000 Fuss) long, and lie 9 feet 3 inches to 20 feet 7 inches (9 to 20 Fuss) underground. There are seven iron doors for flushing, forty-five side-entrance shafts for cleansing, eighteen ventilating shafts, and ten outlets for rainwater. The street drain-pipes, of earthenware, 9·05 inches (9·18 Zoll) diameter, have a total length of 40,474 yards (118,000 Fuss), and carry off the water from the surface of the roads and roofs through four hundred and twenty gratings. Arrangements are made for preventing the sewer gas from entering the houses, and the ventilation of the sewers is provided for by three hundred and ten manholes, and one hundred and eighteen ventilating shafts projecting slightly above the roadway, the openings of which are closed by the pressure of gas from within, unless they are opened purposely and filled with charcoal. From the main sewers the sewage is conveyed by two wrought-iron pipes 18·53 and 27·8 inches (18 and 27 Zoll) in diameter, 15 feet under watermark, through the Mottlau to the pumping station on the island, there being a fall of 1 in 1,500 in the old town, and of 1 in 2,400 in the "Niederstadt." The flushing is performed in twenty days by six men. Before entering the pumping station, the sewage passes through two rotating sieves that separate the solid matter. Two Woolff's steam-engines of 60 HP. each, either of which is able to do the work, drive the sewage through 10,400 feet (10,100 Fuss) of cast-iron pipes 20 inches (22 Zoll) in diameter to the "Riesenfelder," a tract of dunes outside the town. There have been brought under cultivation 252 acres (400 Morgen), and, as grass did not seem to prosper, turnips, maize, tobacco, vegetables, grain and oats have been sown. During 1873, about 48 acres (75 Morgen) produced 423 bushels (280 Scheffel at 85 Pfund), and were sold on the spot at $4\frac{3}{4}d.$ per bushel. The vegetables returned a gross sum of £16 10*s.* (110 Thaler) per

morgen. The other results were equally satisfactory, and the odour was not considered so bad as that of a freshly manured field. The entire cost is calculated at £105,000 (700,000 Thaler).

J. D. L.

Utilisation of the Sewer Water of Paris for Agricultural Purposes. By M. Alfred Durand-Claye.

(Bulletin de la Société d'Encouragement, October 1874, pp. 540–544.)

The sanitary condition of large towns has, of late years, become a matter of so much importance as to demand the serious consideration of municipal authorities. The massing together of populations, and the increase of manufactories producing large quantities of detritus, have endangered health, and the rate of mortality continues high in all towns which have neglected suitable sanitary precautions. Since 1837 sewers have been constructed in Paris to carry off the refuse water. In 1850 their length amounted to 88·7 miles; at present it amounts to 372·6 miles. They follow the lines of the streets upon each bank of the Seine, and terminate in two main sewers, one for each side of the river. Into these the refuse water from the houses, and that used for the public service in the streets, is discharged. The main sewer on the left bank is carried under the river by a syphon placed on the up-stream side of the Alma bridge. It subsequently joins the main sewer on the opposite bank, and their united contents are poured into the Seine at Clichy below the Asnières bridge. A third system of drains receives the liquid refuse of Montmartre, La Chapelle, Belleville, Saint Denis and Bondy, and discharges into the Seine above the Saint Denis canal.

The volume of water thus collected varies with the time of the year and the requirements of the municipal service, but the average daily discharge exceeds 44 million gallons at Clichy, and amounts to nearly 9 millions at Saint Denis. The total discharge into the Seine is 672 gallons per second. The water in the main sewer contains, in 220 gallons (1 cubic mètre) 5·06 lbs. of foreign matter, one half of which is composed of solid substances held in mechanical suspension, and the other half of those in solution and suitable for manure. The analysis of the foreign matter in the 220 gallons gives, among other things, 586·3 grains of potash, 663·5 grains of nitrogen, and 262·3 grains of phosphoric acid. The refuse water from the neighbourhood of Saint Denis is of a very impure character, and in 220 gallons there are 7·9 lbs. of foreign matter, including 2,160 grains of nitrogen. These figures are sufficient to show what an injurious effect the drainage of Paris must produce upon the Seine. In one year upwards of 196,500 cubic yards of refuse are poured into it. The putrescible soluble products, and the noxious gases arising from the fermentation of the sewage, pollute the river for a great distance. A bar

was created at Clichy, which stopped the navigation, and so seriously interfered with the course of the river, that the authorities have been obliged to maintain a permanent system of dredging, which involves an annual expense of £8,000. In addition to the material evils resulting from this condition of the city, a very pernicious effect is produced upon the riparian inhabitants of the Seine. Continual complaints emanate from those inhabiting the districts below Clichy, and it has become necessary to promptly remedy the present state of affairs. All that has hitherto been done is to remove to the exterior of Paris a portion of those causes of insalubrity from which it desires to be free.

The different remedies which have been employed under similar circumstances were inquired into. A commission was appointed in 1866 to report upon the matter, and M. Mille, the engineer-in-chief, was deputed to visit other countries, with the view of ascertaining what course of action had been followed by them. He found that at Valencia, Milan, and Edinburgh, the sewage water had been employed for years past in the irrigation of the soil.

Of the various systems in operation, three merit particular consideration. The first is that of filtration. The experiments with regard to this method, in France and neighbouring countries, have demonstrated the impossibility of its extended application. Nothing is easier than to filter a small quantity of foul water, and to remove the deposits. But when it becomes necessary to filter 53 million gallons of water per day, or nearly 20,000 million gallons per annum, and to cleanse the filter beds each day of over 3,000 tons of solid refuse, the practical difficulties become too great. Moreover, filtration does not remove all the soluble substances in the sewage water, but leaves a quantity of nitrogenous matter, salts of potash and other putrescible ingredients, sufficient to pollute a river.

The late M. Le Chatelier proposed to clarify sewage water by sulphate of alumina, which causes a double decomposition, and forms a mass with the solid ingredients. This method was tried, as an experiment, in filtering tanks near the main outfall at Clichy, with satisfactory results. A quantity of sewage water exceeding 22 million gallons was so treated, and the solid residue, volume for volume, was equal in quality to that of good farmyard manure. The cost of the process was about one penny for every thousand gallons of liquid so treated. The method is still used as an aid to irrigation, and as a means of clarifying water which cannot be made serviceable for any other purpose.

The third method consists in the direct employment of sewage water for the irrigation of the soil. To the effects of this system must be ascribed the fertility of the plains of Milan, of the fields near Edinburgh, and of the gardens of Valencia. In 1867 some land near Clichy was placed under irrigation, when the soil absorbed annually 3½ million gallons of sewage water per acre. The produce of this method of cultivation was of an excellent description; an acre of marsh land thus treated yielded a gross

profit of £71, and the purified effluent water contained but a small quantity of nitrogenous matter.

The success of these experiments determined the Parisian authorities to make a trial upon a larger scale. A couple of engines, each of 40 HP., were erected upon the left bank of the Seine. They pump daily 1,320,000 gallons of liquid into a sewer nearly 1 mile in length, which passes over the bridge of Clichy, and is connected with a reservoir situated between Asnières and Gennevilliers, from which the sewage flows over the whole plain. The authorities of the city of Paris have acquired about 15 acres of land, in the vicinity of this reservoir, to carry out experiments; and have also made arrangements to supply the liquid sewage to any one desiring it. Instead of 15 acres, 100 acres are now under irrigation. The product per acre amounts to 40 tons of potatoes, 200 tons of beetroot, for cattle feeding, and 80 tons of lucerne in two cuttings. The permeability of the soil is so great that in two months it absorbed 210,000 cubic yards of water per acre.

The war in 1870–1871 interrupted the experiments, but in 1872 they were recommenced, and the city voted £40,000 towards them. By means of a deviation the contents of the main sewer of St. Denis were delivered at the bridge of St. Ouen, at an elevation sufficient to enable them to be carried over the bridge without pumping; thus placing 9 million gallons of water, rich in manurial elements, at the disposal of the farmers, for the purposes of irrigation.

At Clichy an engine of 150 HP. lifts nearly 9½ million gallons of liquid out of the main sewer, passes it over the reconstructed bridge of Clichy, and discharges it into drains situated on the left bank of the Seine. Double centrifugal pumps of special construction, working at low speed, lift, together with the liquid contents of the sewers, any impurities and solid ingredients which they may contain, without the use of a strainer or gridiron. The result of these arrangements has been to utilise for irrigation, since the commencement of 1874, the sixth part of the water in the Paris sewers, a quantity due to a population of three hundred thousand, inhabiting a city abundantly furnished with fountains, and exceedingly well watered.

At present, the labours of the municipal authorities are principally directed towards increasing the number of the carriers, or channels of distribution, so that the whole plain may be adequately supplied. Although, at first, owing to the excessive porosity of the soil, 9 million gallons of water were distributed over 1 acre, yet subsequently the quantity has been reduced to exactly one-half, which is sufficient for general cultivation. The extension of the distributing channels is indispensable in order to insure the utilisation of the liquid.

The result of these works is deserving of attention. So far as concerns the purification of the liquid, it is found that the effluent water contains but 1 or 2 parts of nitrogen, instead of the original 44. From an agricultural point of view, the improvement is equally manifest. Cabbages, asparagus, artichokes, beetroot, and

salads thrive well, and find a ready sale. Plants of a more delicate character, such as mint, flowers, and fruit-trees, are also grown on the land. The gross yield per acre varies from £24 to £48 in the open fields; but in the more sheltered and better cultivated parts of the ground it has amounted to even £112.

The utilisation of the sewer water of Paris on the plain of Gennevilliers, containing an area of 800 acres of sandy soil, is now practically carried out. If from any cause this area should be found insufficient, there would be no difficulty in extending the base of operations over the territory of Chatou, which would afford an additional 1,600 acres. Other land, equally well adapted for irrigation, can also be procured.

C. T.

Dresden Waterworks. By Herr Salbach.

(Protokolle des Sächsischen Ingenieur-Vereins, May 10, 1874, pp. 17–41, 1 pl.)

After some introductory remarks about the question of water supply for large cities, as now understood in Germany, and about the laws of natural and artificial filtration, the Author proceeds to describe the valley of the Elbe. This is formed partly of granite, and partly of deposits of a later period, underlying considerable depths of clear, fine sand, such as the large tract known as the Dresden Heath, through which water percolates with great rapidity. As the few open springs yielded only a slight quantity of water, it was surmised that the underground watercourses must be rich; but borings made in 1867, on the summit and slope of the heath, showed that nothing approaching to the required quantity could be drawn from that source. The Author, having previously executed waterworks for the city of Halle, was applied to by the town council to commence experiments with a view to supply Dresden with naturally-filtered water taken from the banks of the river. These experiments showed that a large number of the subterranean watercourses on the slope of the Heath run into the gravel of the Elbe valley, and continue their course under the bed of the river. In the winter, while the Elbe was covered with ice, a shaft 23 feet (7 mètres) deep, and 5 feet (1·5 mètre) in diameter, was sunk in the adjacent bank, and about 660 gallons (3 cubic mètres) per minute were pumped out of it during several weeks, so that the water level of the shaft became permanently 8 feet 2 inches (2·5 mètres) lower than that of the river; the former having a constant temperature of 47° 7′ Fahr. (7° Reaum.), and the latter of freezing point, though only a few feet removed. This, and the fact that the chemical properties of the two waters were materially different, showed that there was not the slightest connection between them. Subsequently, when mains had been put down, several portable engines, each working two centrifugal pumps, were set to work for several months, at a time

when the Elbe was unusually low. It was then found that the quantity of water available was much greater than had been anticipated, and the original project was consequently modified so as to provide for a consumption of 11,000,000 gallons (50,000 cubic mètres) in twenty-four hours, being 55 gallons (250 litres) per head for the two hundred thousand inhabitants. The water from both sources, having been chemically examined, gave the following results:

One Million parts contained from	Total.	Organic Matter.	Mineral Matter.	Chlorides soluble in Alcohol.	Sulphates soluble in Water.	Carbonates soluble in Hydrochloric Acid.	Total Hardness.	Permanent Hardness.
		per cent.	per cent.	per cent.	per cent.	per cent.		
Well	82	6 = 7·3	76 = 92·7	7 = 8·5	18 = 22	51 = 62·2	2°	1°·9
River	104	23 = 22·1	81 = 77·9	6 = 5·8	17 = 16·3	58 = 55·8	2°·75	2°·5

The well water was limpid, colourless, and of pleasant taste; it underwent no change after standing a long time, and the liquid had to be evaporated to one-fifth of its volume before the mineral salts separated. There were no traces of ammonia or nitric acid. The river water was opaque and yellow, leaving a heavy deposit after standing, without losing its yellow colour or unpleasant taste. After evaporation there remained a brown-yellow hygroscopic substance, which burned with difficulty and with a disagreeable smell. Nitric acid was detected in large quantity, and traces of ammonia were apparent. The comparison showed that the Elbe water contained four times as much organic substance as the well water, and that this organic matter was rich in nitrogen.

Between the steep right bank and the river there was a piece of reclaimed land protected by a dam, and only flooded at high water. Though covered with layers of slime, this consisted of the purest gravel extending to the granite, a depth of 65½ feet to 82 feet (20 mètres to 25 mètres), through which the subterranean courses run almost parallel to the river. To intercept these, a line of cast-iron asphalted pipes was laid on the right bank 6½ feet (2 mètres) under low-water mark. These pipes varied from 17·7 inches to 25·5 inches (0·45 mètre to 0·65 mètre) in diameter, and were of the collective length of 4,718 feet. They were provided with a number of slits, to facilitate the entrance of water, and were surrounded by gravel, carefully sifted to the size of nuts and peas, to prevent any smaller material from entering the pipes. The pumping station was erected about the centre of this 'gallery.' There were two collecting wells, each 23 feet (7 mètres) in diameter, and 16 feet 4 inches (5 mètres) in depth under the river datum. These wells were 131 feet (40 mètres) apart, and were so connected by pipes, that all the water could be collected in one well, while the other was shut off. The wells were built of sandstone blocks

cemented watertight, on a strong wooden frame strengthened with iron bolts, and gradually lowered to a sufficient depth, while portable engines pumped out the water. The connecting pipes were put in beforehand, so as to allow the water to commence to flow immediately the wells had reached a sufficient depth. The works were begun in the autumn of 1871, and finished about June 1874; they were frequently interrupted by the rising of the Elbe, and arrangements had to be made for clearing everything out of the way of the water within twenty-four hours.

The level of the water in the wells being 11½ feet (3·5 mètres) below the river datum, the pumps could not be erected more than 9 feet 10 inches (3 mètres) above that datum; but as the Elbe had been known to rise to 26 feet (8 mètres) above this point, a watertight area had to be constructed for the entire pumping station. There are six steam-engines of Woolff's horizontal pattern, which can be used in pairs, or separately. The pumps are horizontal and double-acting. The diameter of the smaller cylinders is 20½ inches (0·52 mètre), and of the larger 47 inches (1·2 mètre), with a length of stroke of 49 inches (1·25 mètre). The diameter of the pumps is 18½ inches (0·47 mètre), each of them delivering 82 gallons (0·372 cubic mètre); the diameter of the fly-wheel is 16 feet 4 inches (5 mètres). There are six tubular boilers, each with a heating surface of 1,453 square feet (135 square mètres), a diameter of 74 inches (1·88 mètre), and a length of 81½ feet (5·65 mètres).

A high-pressure reservoir is situated on the summit of the Dresden Heath, at a distance of 1,312 yards (1,200 mètres) from the pumping station; its highest water level being 196 feet 10 inches above the river datum. It is rectangular in form, and is divided into two equal parts, each half having an area of 2,356 square yards (1,970 square mètres), and at the greatest height of water, 16 feet 4 inches (5 mètres), it has an aggregate capacity of 4,224,000 gallons (19,200 cubic mètres). The bottom of this reservoir is of concrete from 1 foot 11 inches to 2 feet 7 inches (0·6 mètre to 0·8 mètre) thick, on which is placed a single layer of brick in cement; the sides, division wall, and transverse arches are of sandstone. The pipe for conveying water from the pumping station is 25·5 inches (0·65 mètre) in diameter, while the town mains are 29·5 inches, 23·6 inches, 17·7 inches (0·75 mètre, 0·60 mètre, 0·45 mètre) in diameter; those in the side street being from 11·8 inches to 3·9 inches (30 centimètres to 10 centimètres).

At every 87 yards (80 mètres) there are fire-cocks from which, by means of hose, water may be thrown over the highest houses. The mains are of cast iron, asphalted, and subjected to a pressure of 12 atmospheres from within, and simultaneously to a series of blows with sledge-hammers from without, after which they are submitted to a pressure of 15 atmospheres. The entire network represents a length of 70 English miles (18 German miles), and a

weight of nearly 10,000 tons. The cost is calculated at £385,012 (2,566,750 thalers at 3*s.*), the particulars of which are:

	£.	Thalers.
Construction of wells	23,700	158,000
Pumping-station buildings	78,667	524,450
Engines	33,000	220,000
Reservoir	34,995	233,300
Piping	208,350	1,389,000
Other expenses	6,300	42,000

J. D. L.

Gas-holder Explosions. By Herr Schiele.

(Journal für Gasbeleuchtung, No. 13, 1874, pp. 468–479.)

At the last General Meeting of the Association of Gas and Water Engineers of Germany, Herr Schiele read a Paper describing a remarkable explosion of a gas-holder at Coblentz. It had a diameter of about 75½ feet (23 mètres), was quite new, and had never been used. When the tank had been about half filled with water, the man-holes were closed to test the tightness of the upper parts of the holder. This having been found satisfactory, gas was allowed to pass into the holder, so as to raise it still further out of the water for the purpose of examining the joints in the lower part. It was then determined to empty the holder of the mixture of air and gas which it contained; but whilst this was going on a violent explosion took place. The water in the tank was dispersed in the form of fine rain, the holder was blown into the air, the crown being completely torn away. A guide-roller was detached, and thrown to a distance of about 100 feet, burying itself in the earth. One of the girders connecting the upper ends of the columns was thrown down, and the holder, which had turned over, fell partly in the tank, and partly on the ground. The crown, with its internal bracing, had likewise executed a summersault, and was crumpled up in a position similar to the other part of the holder. A strict investigation was made as to the cause of the explosion, when, as it was ascertained that no light was near, and all other theories being in the Author's estimation inadmissible, he arrives at the conclusion that it was due to the spontaneous combustion of a piece of oiled waste accidentally dropped into the inlet pipe. The Paper contains an elaborate discussion of the opinions of various authorities as to the proportions of the mixtures of atmospheric air and gas which are explosive, with a calculation of the probable composition of the gaseous contents of the holder in question at the moment of explosion.

R. B. P.

Submerged Gas and Water Mains. By H. Janssen.

(Journal für Gasbeleuchtung, No. 14, 1874, pp. 495–503.)

In his introductory remarks the Author, after mentioning several projects for laying mains, and the publications in which the details are to be found, passes on to a particular account of two such mains at Berlin, one for conveying water across a canal to supply the Zoological Gardens, the other to convey gas across the River Spree. Both were executed by the firm of Oechelhaeuser. The configuration of the main was in each case the same, consisting of a central straight length, put together with flange joints and india-rubber or hemp packing, which rested in a shallow channel previously dredged in the bottom, with inclined branches at each end following the slope of the banks. In the first case the main was 105 feet (32 mètres) in length, having a diameter of 15·35 inches (390 millimètres), with a thickness of $\frac{5}{16}$ inch (8 millimètres). The central straight portion was in two lengths, which were put together on the side of the canal, bends of the proper angle to receive the shore lengths being attached at each end. The ends having been plugged, the main was rolled into the canal, when its buoyancy was sufficient to cause it to float; but to insure the mouths of the bends being presented upwards two casks were attached at each end. The shore ends were suspended horizontally from shears exactly over the spot they were intended to occupy, and the central portion was floated into position across the canal. One end of the main was now raised a little distance out of the water, by a windlass fixed on a platform carried by two barges, lashed together and kept in position by anchors and guy ropes from the shore. At the same time the suspended shore length was lowered to enable the joint to be made, the plug being removed, and the main was then allowed to sink into the water. The barges and platform being transferred to the opposite side of the canal, the other end of the main was raised and connected with the shore lengths as before. Water being pumped into the tube, it was lowered gradually to the bottom.

The gas main across the Spree, from Charlottenburg to Moabit, was laid in a somewhat similar manner. The total length was 259½ feet (79·3 mètres), with a diameter of 10¼ inches (260 millimètres), and a thickness of $\frac{5}{16}$ inch (8 millimètres), the central straight piece, which was in eight lengths, measuring 177⅓ feet (54 mètres). The bends served as collecting boxes for the products of condensation deposited by the gas. This central length was put together at the side of the river on floating stages, each consisting of two casks lashed together, and the main was lowered into position in the bed of the river by means of shears. Small wrought-iron pipes were pushed down the main and introduced into the collecting boxes, for removing the products of condensation as circumstances should require.

R. B. P.

Mosel-Saar Canal. By Herr Knobloch.

(Deutsche Bauzeitung, No. 53, 1874, p. 214.)

Alsace-Lorraine is well provided with canals, amongst which are the Rhine-Marne canal, the Rhine-Rhone canal, the Saar Coal canal, and the canalised Mosel. All these are State property, free of tolls. Before the province was added to the German empire, the Government intended to complete the network, by constructing a side canal from Strasburg to the Rhine, by continuing the Mosel canalisation from Frouard to Metz and Diedenhofen, and by connecting Metz by canal with the Saar at Saarbruck. The war interrupted the proceedings; but immediately after its termination the new Government ordered the preparatory work to be commenced. The existing canal from Saarbruck to Metz is 125½ miles (202 kilomètres) long, the projected canal only 41 miles (66 kilomètres); and, as the present canal passes through French territory, shipping may be subject to difficulties, an additional reason why its completion is eagerly desired. It will be used chiefly for the transport of coal from the rich Saarbruck mines, and the mineral and agricultural products of Alsace-Lorraine. The preparatory works were begun in December 1872, and are approaching completion.

The great question was how to supply the canal with water. The French engineers before the war had decided to pump the water from the Mosel into it, the difference of level at the highest point being 151 feet (46 mètres). As the canal would cross the drainage of three brooks, with large watersheds, it was surmised that, at the lowest watermark, these three brooks would afford an adequate supply in summer calculated at 21·18 cubic feet (0·6 cubic mètre), and throughout the year at 10·59 cubic feet (0·3 cubic mètre) per second. By gauging these brooks at different points, it was found that at low water they would contribute more than the maximum required by the canal, and the possibility of construction on this principle was plainly shown. The canal commences in the harbour of the canalised Mosel at Metz, and will reach the summit of the Mosel and Nied watershed, 46 mètres higher, by eighteen locks of 8½ feet (2·6 mètres) fall each, and continue through the Nied valley for 25 miles (40 kilomètres). At Teterchen it crosses the watershed between the Nied and Bist in a tunnel of 2 miles 142 yards (3·35 kilomètres), and from the mouth of the tunnel will decline into the Bist valley by sixteen locks, joining the Saar 10½ miles below Saarbruck. There will be an aqueduct of stone and iron 98½ feet (30 mètres) in width. A railway is carried across the canal twice. The total cost will be about £900,000 (6,000,000 thalers).

J. D. L.

Gravelle Lock on the St. Maurice Canal. By M. Dardart.

(Annales du Génie Civil, Nos. 8 & 11, 20 pp., 2 pl.)

The St. Maurice canal connects the St. Maur canal with the Seine below Charenton, and the Gravelle lock is situated about 328 yards (300 mètres) from the junction. The fall of water at the lock is 9 feet 4½ inches (2·86 mètres). The depth of water in the reach above the lock is 8 feet (2·45 mètres), but only 5¼ feet (1·6 mètre) below it; the slopes of the banks are 2 to 1, and the bottom width is 49 feet (15 mètres). The boats employed on the navigation are flat-bottomed, 147 feet (45 mètres) long, 24¼ feet (7·4 mètres) broad, their greatest draught being 4½ feet (1·4 mètre). An aqueduct passes under the upper entrance of the lock, leading water from the Marne for turning two mills on the right bank of the canal, and an iron bridge crosses the lower entrance.

The distance from the line of the upper return walls to the point of the head cill is 44 feet (13·4 mètres); between the gates 167¼ feet (51 mètres), and from the point of the tail cill to the line of the lower return walls 37 feet (11·3 mètres). The projection of the point of the cills is 4 feet 11 inches (1·5 mètre), and the distance of the point of the head cill from the lift wall is 5 feet 10 inches (1·78 mètre). The width of the lock is 25 feet 7 inches (7·8 mètres). The depths from the coping of the side walls are as follows: to the upper gate floor 19 feet 1½ inch (5·83 mètres); to the head cill 18 feet 1½ inch (5·53 mètres); to the springing of the invert 22 feet 8 inches (6·93 mètres); to the bottom of the invert 23 feet 6½ inches (7·18 mètres), and to the lower gate floor 23 feet 10 inches (7·26 mètres). The face of the retaining wall at the back of the upper cill is a concave arc whose versed sine is 3 feet 4 inches (1·02 mètre). The side walls of the lock chamber are 9½ feet (2·9 mètres) wide at the bottom, and 7 feet 10½ inches (2·4 mètres) at the top. The thickness of the invert is 6½ feet (2 mètres) at the springing, and 5¾ feet (1·75 mètre) in the centre; the upper gate floor is 12 feet 1½ inch (3·7 mètres) thick, and the lower 5½ feet (1·67 mètre).

The foundations of the lock consist of a layer of concrete, averaging about 3¾ feet (1·15 mètre) in depth, inclosed by stakes and boards, and resting upon a clay bed consolidated by stakes driven down about 3¼ feet (1 mètre), and 1⅝ foot (0·5 mètre) apart. There are stone aprons at each extremity of the lock, extending slightly beyond the return walls and terminated with radiating quoins 1⅝ foot (0·5 mètre) deep. The top of the retaining wall at the back of the upper cill is constructed with ashlar quoins, radiating to the curve of the face, from 1⅓ foot to 2¼ feet (0·4 to 0·7 mètre) thick: the tail cill is also of radiated ashlar of similar thickness. The walls are in courses, with bonded ashlar masonry at the quoins. The coping, in general, is 3¼ feet (1 mètre) wide,

with paving behind $1\frac{5}{8}$ foot (0·5 mètre) in width: the quays have a slope from the walls of 1 in 74.

The aqueduct, where it passes under the lock and side walls, consists of a segmental arch resting upon piers $26\frac{1}{4}$ feet (8 mètres) apart, and $3\frac{1}{4}$ feet (1 mètre) high, with a concrete invert below; the rise of the arch is $5\frac{1}{4}$ feet (1·6 mètre), and its thickness at the crown $3\frac{1}{4}$ feet (1 mètre). The arch of the aqueduct, on either side of the lock, is semicircular, and the piers are $8\frac{1}{2}$ feet (2·6 mètres) high. The total length of the covered aqueduct is $119\frac{1}{2}$ feet (36·4 mètres).

L. V. H.

Damming of the Chéliff. By M. Lamairesse.

(Annales des Ponts et Chaussées, June 1874, pp. 569–622, 2 pl.)

The Chéliff, which rises above Amourah in Algeria, and flows into the Mediterranean at Mostaganem, has been dammed across, where it passes through a narrow defile above Orleansville, to provide for the irrigation of 29,652 acres (12,000 hectares), and it is expected that 19,768 acres (8,000 hectares) above the dam will become capable of being cheaply irrigated, owing to the impounded water raising the subterranean springs in the alluvial plains along the upper portion of the river. The discharge of the Chéliff at that point is never less than 330 gallons (1,500 litres) per second; it averages about 1,760 cubic feet (50 cubic mètres) in winter, and reaches 38,800 cubic feet (1,100 cubic mètres) during excessive floods. The bottom of the culvert for conveying the water is 7 feet $2\frac{1}{2}$ inches (2·2 mètres) below the top of the weir, which is 38 feet $6\frac{1}{2}$ inches (11·75 mètres) above the bed of the river; and thence a conduit, capable of discharging 1,760 gallons (8,000 litres), brings the water to the upper part of Orleansville with a uniform fall of 1 in 3,030. The backwater of the dam, when the water is level with the top of the weir, extends to a distance of $6\frac{1}{4}$ miles (10 kilomètres), but a rise of 13 feet (4 mètres) over the weir would not cause any damage up the river. The water retained between the bottom of the culvert and the top of the weir amounts to upwards of 176,600,000 cubic feet (5,000,000 cubic mètres). The front of the weir is concave, with a versed sine of 18 feet 8 inches (5·7 mètres) at the top; the distance between the side walls being 276 feet (84·2 mètres) at the top of the weir, and 190 feet (58 mètres) at the bottom. The back of the dam has a batter of 1 in 20; the front, of ashlar masonry, was commenced with a batter of 1 in 2, but as the overflowing water injured the foot of the dam the design was altered, the face being made with a batter of 1 in 3 for the upper $17\frac{1}{4}$ feet (5·25 mètres), followed by a slope $19\frac{1}{2}$ feet (5·94 mètres) long, with an inclination of 2·15 to 1, and then a batter of 1 in 3 again to the bottom; the fall of the water is thus broken by the slope, which in the worst floods it has not overshot.

The dam is 8 feet 2½ inches (2·5 mètres) wide at the top, and 38 feet 9½ inches (11·83 mètres) at the bottom, which is wider than stability requires; and spaces would have been left in the interior had the masonry been less advanced when the design was modified. Two discharge outlets are situated in the dam near the left side, each 4 feet 11 inches (1·5 mètre) wide, and 7 feet 4½ inches (2·25 mètres) high, their cills being 9 feet (2·75 mètres) below the top of the weir. There is also a bottom sluice, the cill of which is 34 feet 7 inches (10·55 mètres) below the top of the weir, and 4¾ feet (1·45 mètre) wide; it was used during construction in drawing off the water on the upper side of the dam in the dry season, and also in keeping the water from overflowing the weir whilst repairs were being executed in front of it. The sluice would have been more serviceable if it had been larger. The culvert for conveying the water supply is built in the left side wall; its section is the segment of a circle of 4¼ feet (1·3 mètre) radius, and it is 7½ feet (2·3 mètres) high. The dam, commenced in 1868, was executed in two portions, coffer-dams being constructed from each bank consecutively; the river being allowed to flow over the one half, and through a gap in the centre, whilst the other half was being raised.

The foundations, supposed at first to be rock, proved eventually to consist of varieties of clays, marls, sandstones and limestones; this great diversity of formation is due to a considerable dip in the thin strata which form the river bed. The floods washed away portions of the dam during construction; and after it was completed, in 1870, it became necessary to underpin the foundations, and to repair the platform on the river bed below. This platform had been made with pitching, and with a counter dike about 33 feet (10 mètres) from the dam, thus forming a basin of water, which was 4 feet (1·2 mètre) in depth, for checking the shock of the water falling over the dam. It was found that the rubble platform, beyond the dike, had been destroyed; the falling water had communicated its motion to the water in the basin, which proved too short; the water had then undermined and washed away portions of the dike; it had next worked under the pitching which formed the bottom of the basin; and, lastly, had commenced to undermine the dam and side walls.

The foundations of the dam and side walls were carried deeper, and the new platform was built on a lower and more solid foundation, below any possible scour. It was formed of pitching and concrete, and was protected near the dam with concrete blocks. The dike was abandoned, and the platform prolonged with a gradual rise, forming a basin 164 feet (50 mètres) long. This basin and the modified dam have not sustained any serious damage.

The best platform below a dam would be a solid and smooth one, with a gentle slope, followed by a platform almost horizontal; but when circumstances do not admit of this, a basin as formed in the present case is the best substitute.

L. V. H.

Reconstruction of the Château-Gontier Bridge. By M. Legras.

(Annales des Ponts et Chaussées, March 1874, pp. 227–246, 1 pl.)

The original bridge at Château-Gontier, over the river Mayenne, on the high road to Caen, having been destroyed for strategical purposes on the 17th of January, 1871, the structure was rebuilt with slightly different dimensions, and opened for traffic on the 16th of November, 1872. As it was the only bridge connecting the two banks of the Mayenne for a distance of 30 miles (50 kilomètres), communication was in the meanwhile established by a bridge of boats, completed in forty-eight hours, in spite of most unfavourable circumstances arising from a packing of ice, accompanied by a considerable flood. The rise of the river during floods rarely amounting to 4 feet 1 inch (1·25 mètre), the level of the platform of the bridge was fixed at about that height above the level of low water. The site chosen was a short distance below the destroyed bridge, where the river has a width of 60 yards (54·65 mètres). Of the six boats one measured about 100 tons, three 60, 50, and 40 tons, and two smaller ones of 20 and 25 tons were coupled together. The structure consisted of six spans, varying in length from 20 feet 4 inches (6·2 mètres) to 14 feet 9 inches (4·8 mètres), on account of the different displacements afforded by the boats. The platform was constructed with a small camber up stream, the better to resist the force of the current. It had a width of 18 feet 5 inches (5·62 mètres), and consisted of a footway for passengers and a roadway for a single line of vehicles. To prevent the stoppage of the navigation, it was necessary to make arrangements for the opening of one span of the bridge: this was effected by a framework of two transverse timbers 3 inches by 8 inches ($\frac{0·08}{0·2}$ mètre), laid flat, of a length rather greater than the width of the bridge, and placed parallel to the bank. To these two timbers six longitudinals 7 inches by 12 inches ($\frac{0·18}{0·30}$ mètre), were bolted at intervals equal to those of the six bridge longitudinals. A hole was then bored in a horizontal line through all the twelve to receive a 2-inch (0·05 mètre) pin, forming the axis about which the lifting span moved. The framework being ballasted and planked over, the platform at the other end of the span was sawn across, and means afforded for raising it by tackles worked from the shore.

The ruined bridge, of which only the walls of the abutments and the foundations remained intact, consisted of three segmental arches of 49 feet 3 inches (15 mètres) clear span, and 6 feet 9 inches (2·06 mètres) rise, supported on two piers 6 feet 7 inches (2 mètres) in width, and two abutments of a depth of 21 feet 4 inches (6·5 mètres). The old bridge having afforded an insufficient passage, both in width and height, for boats during floods, it was resolved to increase the waterway by 26 feet 3 inches (8 mètres), divided equally between the three spans. The springing of the

arches being fixed at the same level as before, the old materials could be employed, and the original curve of the intrados was merely produced to suit the increased span, thus raising the crown 3 feet (0·9 mètre). A corresponding rise in the crown of the extrados could not have been carried out without rendering the approaches almost impracticable, but by reducing the thickness of the arch at this part, and also that of the road material, the additional rise of the roadway was reduced to 1 foot 1 inch (0·33 mètre).

In consequence of the new arrangement, the foundations of the piers had to be placed 4 feet 4 inches (1·33 mètre) nearer the banks, and the abutments were put back 13 feet $1\frac{1}{2}$ inch (4 mètres). Thus the new foundations had a part in common with the old, which gives a certain amount of interest to the method adopted in their reconstruction. The old abutments which remained were 21 feet 4 inches (6·5 mètres) thick at the springing of the arch, of which 8 feet $2\frac{1}{2}$ inches (2·5 mètres) could be utilised in the new abutments. Now an abutment is required at the same time to support the weight of the adjacent semi-arch and to resist the horizontal thrust. The old work afforded an incompressible support sufficiently large to carry the weight of the semi-arch and prevent vertical settlement, while the new part, though it might settle under its own weight, would not, in so doing, diminish the resistance to the horizontal thrust of the entire abutment. On account of the inevitable settlement, the new masonry was not bonded into the old, but a space of $\frac{3}{8}$ inch (0·01 mètre), filled with mortar, was left between them. The lengthening of the back of the abutments was carried out during the low water in 1871. On the left bank the foundation of masonry was built on the rock, with the aid of pumping; on the right bank the rock was covered by a bed of compact gravel 5 feet (1·5 mètre) thick, which the quay walls and old abutment prevented from being undermined, and upon which a bed of concrete 4 feet (1·2 mètre) in thickness was placed, carrying the masonry. The new piers having to be built 4 feet 4 inches (1·3 mètre) nearer the banks, to some extent coincided with the old ones, the foundations of which were standing. It was intended to remove the portion common to both, in order to insure equal settlement, by means of a cofferdam built partly on the concrete of the old foundations, and partly on piles driven into the bed of the river; but the dam, proving unequal to resist a head of 13 or 16 feet (4 or 5 mètres) of water during the winter floods, had to be abandoned. The foundations were then laid in concrete, consisting of 1 part of pure hydraulic lime to 2 parts of ballast, lowered to the bottom by means of boxes opening at the lower side. The centrings were struck simultaneously and gradually fourteen days after the closing of the arches. The settlement was $4\frac{7}{8}$, $4\frac{3}{8}$, and $3\frac{1}{2}$ inches (0·125, 0·11, and 0·09 mètre), in the right, middle, and left arches respectively.

Cost of the Work.

	£	Francs.
Clearing and foundations	1,860	46,500
Reconstruction	3,340	83,500
Total	5,200	130,000
Extra cost for laying the foundations of the piers in winter	1,800	45,000
	7,000	175,000

The cost per lineal yard, £111 6*s.*; or 3,070 francs per lineal mètre.
„ per square foot of platform, £1 0*s.* 6*d.*; or per square mètre, 279 francs.

A. T. A.

Traversing Bridge for crossing the Harbour entrance between S. Malo and S. Servan. By M. Floucaud de Fourcroy.

(Annales des Ponts et Chaussées, July 1874, pp. 5–17, 2 pl.)

The towns of S. Malo and S. Servan stand on either side of a large inner harbour, which it was intended at one time to convert into a floating basin. Works for this purpose were authorised in 1836, but have never been completed. The harbour now communicates with the sea by five sluices, two locks (which have never been fitted with gates), and an entrance 328 feet wide (100 mètres), the bottom of which is about 34 feet (10·4 mètres) below the level of equinoctial springs. At spring tides this bottom is dry on the ebb for several hours, but at neaps it is always covered. The great rise of tides in this locality produces strong currents through the entrance at ebb and flow.

Until recently the only means of crossing this entrance was by boats when the water was in, or at low-water spring tides by traversing a sort of causeway, formed by the foundations laid for the inner wall of the dam intended to be thrown across the mouth of the harbour. Flights of steps were placed at each side to facilitate this passage, which was, however, inconvenient, and productive of accidents.

Under these circumstances, M. Leroyer, architect, of S. Servan, obtained leave, in 1873, to construct for this passage what may be termed a 'traversing bridge,' since its principle more nearly resembles that of a railway traverser than any other structure. In outward appearance it is somewhat like the elevated tanks at railway stations. It consists of a platform raised to a height of 36 feet (11 mètres) on four columns of wrought iron. These rest on a frame, carried on four wheels, which run on a line of rails across the bed of the harbour. The platform is thus on a level with the quays at each end, so that the passengers have simply to step from one to the other. When not in use, the bridge stands in a recess, out of the way of the shipping, on the S. Malo side;

and it is moved by chains attached to the lower frame or truck, and lying on the bottom, so as to offer no impediment to the navigation.

The Vignoles' rails used for the road are 77 lbs. to the yard (38 kilogrammes per mètre), resting on longitudinal and cross sleepers bedded in large stones or concrete. The bottoms of the rails are raised about 2 inches (0·05 mètre) above the sleepers by occasional packing pieces, thus permitting the water to run underneath them and to wash away any accumulation of sand. This plan has hitherto proved successful. The gauge is 15 feet (4·6 mètres). The platform of the bridge is about 23 feet by 20 feet (7 mètres by 6 mètres), supported by four pillars of wrought iron, spaced 13 feet (4 mètres) apart, and 4 inches (0·1 mètre) in diameter. These pillars are stiffened by cross and diagonal bracing at each of the sides, and horizontally at the middle. The wheels of the truck are 3 feet 3 inches (1 mètre) in diameter, and are inclosed in a casing of sheet iron, brought to a point at each end, to diminish the fluid resistance. The total weight of the bridge is 13·8 tons (14,000 kilogrammes), and the immersed section, perpendicular to the direction of motion, is only 59·1 square feet, even taking in the area of all four pillars.

Motion was at first intended to be given by a machine on the bridge itself; but as this plan would have seriously increased the dead weight, it was abandoned for the following:—A chain attached to the southern end of the truck, after passing under a vertical pulley at the foot of the paved slope which forms the boundary on the S. Servan side, is wound on a horizontal drum fixed at the top of this slope. Another chain attached to the northern end of the truck, passes round a horizontal pulley at the S. Malo end, returns under the truck, and, after passing over a vertical pulley at the S. Servan end, like the first rope, is wound in the opposite direction round another drum carried on the same shaft. This shaft also carries three pulleys, placed side by side, of which the middle only is keyed on, the other two running loose. The loose pulleys carry two belts, one of them crossed, which at the other end pass round a drum upon the crank shaft of a steam-engine. It is evident that by simply shifting one or other of these belts from the loose to the fixed pulley, the chain drum is made to revolve in one or the other direction, and the bridge advances or retires accordingly.

An attempt was made to employ self-acting mechanism for shifting the belt off the fixed pulley at the end of the bridge's travel, there being a danger that if this were at any time neglected by the workman in charge, the bridge would be brought violently up against the pier which it was approaching. This was, however, abandoned, because, as the bridge was sometimes out of water, sometimes immersed, sometimes heavily and sometimes lightly laden, it was found requisite to shift the belt (and so take off the traction) earlier in some cases than in others; moreover, the passing of a vessel, or other causes, sometimes rendered it necessary

to stop or reverse the motion in the middle of the travel. In place of this, therefore, a system of signals was introduced, by means of a trumpet similar to that occasionally used at the level crossings of railways. The possibility of a heavy shock is provided against by short landing stages at each end, which, by means of a counter-weight, act as springs, closing in towards the pier when struck by the bridge, and returning to their former position when the bridge starts on its next trip. The amount of movement given to these is 3 feet 3 inches (1 mètre).

Before being set to work, the bridge was subjected to careful tests. A weight of about 6 tons (6,000 kilogrammes) was left on the platform for twenty-four hours. The bridge was moved under this load, and afterwards under half the load, placed on one side and partly overhanging the wheels. The stiffness and stability were found to be perfectly satisfactory. The bridge was then put to work; but it was necessary to replace the steam-engine, which was of 6 HP., by one of 10 HP., and also to substitute wrought-iron for cast-iron wheels, the latter having in one month worn down to a depth of about $\frac{5}{8}$ inch (0·015 mètre). With these alterations the bridge worked well, and has continued to do so. The time of transit is generally from $1\frac{1}{2}$ minute to 2 minutes, giving a maximum speed of about 2 miles an hour. No difficulty has arisen from bad weather; and the bridge is largely used by the inhabitants of the two towns. From an account kept between December 2nd, 1873, and January 11th, 1874, it appeared that the average number of passengers was 1,832 per diem. The fare is one halfpenny (5 centimes), and it is calculated that a daily total of 1,400 passengers will pay all the expenses of maintenance, and form a depreciation fund, providing for the renewal of the plant within ten years; so that the enterprise would appear to be commercially as well as mechanically successful.

W. R. B.

The Harbour of Spezzia.

Report by M. Maldini, Deputy of the Italian Parliament and Reporter of the Commission on the Defences of Spezzia. Extract by E. Delacroix.

(Revue Maritime et Coloniale, March 1874, pp. 880–897, 1 pl.)

The gulf of Spezzia, on the north-western shores of Italy, lies in a fork of the Apennines from S.E. to N.W., and near the boundary which divides Liguria from Tuscany proper. Its entrance, from a maritime point of view, lies between the small island of Tino on the west, and Cape Corvo on the east, and is $5\frac{1}{4}$ miles ($8\frac{1}{2}$ kilomètres) broad. Between these points a sand bank, covered by $9\frac{1}{3}$ fathoms (17 mètres) of water, forms a breakwater against large sea waves; and from this line the gulf has a length of $6\frac{1}{3}$ miles (10 kilomètres). The bay of Porto-

Venere has an area of 321 acres (1,300,000 square mètres), can receive ships of all sizes, and is now used as a harbour of refuge against westerly winds. The narrow passage to the westward between it and the isle of Palmaria is very shallow, being only 9⅔ feet (3 mètres) deep, and large waves from the west cannot traverse it. The little bay of Castagna is about 40 acres (160,000 square mètres), and can receive the largest ships. The bay of Varignano has an area of 25 acres (100,000 square mètres), that of Grazie 60 acres (240,000 square mètres), and of Panigaglia 100 acres (400,000 square mètres). The town of Spezzia is at the extremity of the gulf, near the centre. On the eastern side is the bay or gulf of Lerica, which in some parts has sufficient depth to allow of the largest ships of war being moored.

The superficies of the gulf is about 2,224 acres (9,000,000 square mètres), and its depth permits of vessels anchoring at almost any part, even on the submarine bank in the middle of the entrance of the gulf. The bottom generally is mud, except in the neighbourhood of La Scola, and of the point Castagna, where it is rocky; there is seaweed in the bay of Santa-Teresa, and sand at several points near the town of Spezzia. Ships usually anchor on the west of the gulf, where the bays are commodious. A high road leads from Porto-Venere to Spezzia, which was constructed by order of Napoleon the First. The arsenal between San-Vito and Spezia covers 222 acres (900,000 square mètres), viz.: 46·25 (187,000) for wet docks and basins; 3·6 (14,600) for building slips; 1·38 (5,600) for buildings and workshops; 158·64 (642,000) for esplanades, roads, and land, comprised in the original project, but of which the destination has not yet been assigned. Outside the wall on the north are the barracks and the hospital, covering together about 2 acres (7,800 square mètres). In the bay of San-Vito, near the arsenal, are the offices and stores for the naval artillery, and ponds for the preservation of timber. This establishment covers 15 acres (60,000 square mètres). On the opposite side of the gulf of Spezzia, near San-Bartolomeo, there is a dockyard which covers 30 acres (120,000 square mètres), containing two building slips, one for hauling up vessels, a small wet dock, offices, stores, &c. It is connected with the arsenal by two roads, one fit for carriages, and the other supplied with rails. In the bay of Fezzano there is a yard for the repair of dredging machines.

For 20 miles to the west of Spezzia the coast is so rocky and abrupt that disembarkation is impossible. On the east, however, near the mouth of the Magra, this is practicable, but the Magra itself is not navigable.

Many proposals have been made for the naval defences of the gulf, mostly based upon the necessity of a 'digue' or mole, slightly submerged, extending nearly across the gulf, and having forts upon it to guard the passage at each end, supported by forts on shore. A commission appointed by the Chamber to examine these, pronounced in favour of a mole between Santa-Maria and Santa-Teresa, the immediate construction of which was recommended.

For the present the gulf of Spezzia will be defended by twenty-six forts or batteries carrying 278 guns. Eight of these works will be armour-plated, and will combine with the mole in preventing an enemy's fleet from forcing an entrance or bombarding the arsenal.

W. J.

Evaporation in Steam Boilers decreasing in Geometrical Progression. By M. Paul Havrez.

(Annales du Génie Civil, August and September 1874, 29 pp.)

M. Havrez commences with a reference to the well-known experiments of Mr. C. W. Williams on the evaporative power of a locomotive boiler divided transversely into several distinct sections, to show the rate of evaporation of the fire-box and of each section of the flue tubes successively, as they recede from the fire-box. He refers also to the experiments of Mr. John Graham, near Manchester, and, finally, to the observations of M. Petiet and the Engineers of the Northern railway of France, on the evaporative value of the different parts of a locomotive boiler divided into five compartments. In these experiments the first compartment comprised the fire-box, having 60·28 square feet of surface (5·6 square mètres), and 16·15 square feet of tube surface (1·5 square mètre). The tubes were divided into four other compartments, each of them 3·02 feet long (0·92 mètre), with 179 square feet of surface (16·62 square mètres). Each compartment held 70½ gallons of water (320 litres), and was fed from a gauged tank by a special pump. The levels were maintained strictly uniform. The mean of fifteen experiments, of which seven were made with coke as fuel, and eight with briquettes, gave the following results of evaporation.

The quantities of water evaporated per hour with coke were, for the—

	Fire-box section.	1st tube section.	2nd tube section.	3rd tube section.	4th tube section.	
	24·5	8·72	4·42	2·52	1·68	lbs. per sq. foot,
or,	119·6	42·6	21·6	12·3	8·2	kilogrs. per sq. mètre ;

and with briquettes—

	36·9	11·44	5·72	3·52	2·31	lbs. per sq. foot,
or,	180·25	55·85	27·92	17·18	11·3	kilogrs. per sq. mètre.

These results confirm the fact, already established by Williams and by Graham, that the evaporative performance of the tube-surface decreases rapidly with the distance from the fire-box.

The Author establishes, by careful analysis of experimental data, the following law :—The quantities of water, evaporated by consecutive equal lengths of tubes, decrease in geometrical progression, whilst the distances from the commencement of the series increase in arithmetical progression. From which it follows that the ratio

between the quantities of water evaporated by consecutive equal lengths is a constant number, N. These ratios are expressed by the equation,

$$Q_L = Q_0 N^L,$$

in which Q_L is the quantity of water evaporated by the $(L + 1)$ length, that evaporated by the first length being $= Q_0$.

The point at which this law begins to prevail, is that at which the radiation of heat from the fuel ceases, and heat is communicated by conduction alone; and it appears from the observations cited, that in locomotive-boilers, the evaporation diminishes by nearly one-half at each interval from mètre to mètre [say, one-half from yard to yard]. The value of N in the above formula, according to the ratio of one-half would be $= 0 \cdot 5$. For large boilers, the Author concludes that the value of N varies between $0 \cdot 5$ and $0 \cdot 7$ for the relative decrease of evaporation from mètre to mètre; but that for small boilers, and small quantities of hot gases, the value may fall below $0 \cdot 5$.

D. K. C.

Surface Condensers. By M. Audenet.

(Revue Maritime et Coloniale, May 1874, pp. 509–540.)

Referring to the economy of fuel, from 15 to 20 per cent., effected by the substitution of surface condensers for injection condensers, M. Audenet calculates that, though the power required to work the air pump is to a great extent economised by the use of surface condensers, yet from the fact that the resistance of the air pump does not exceed $0 \cdot 0024$ HP. per horse-power of the engine, no great economy is possible in that direction. Moreover, towards the end of the Paper, he shows that the ordinary construction of surface condensers offers so great a resistance to the circulation of the condensing water, that the power required to put that water in motion more than counterbalances any saving in the expenditure for the air pump. The point of practical importance in the consideration of the surface condenser, is to determine the relation between the cooling surface, the volume of water in circulation, and the quantity of steam to be condensed and brought down to any desired temperature. In addition to this, it is maintained that, to effect a rapid reduction of pressure in the cylinder, it is necessary above all to provide a quick exhaust, together with a condenser of great capacity, by the mere volume of which the steam when exhausted into it is considerably reduced in pressure, independently of the fall of pressure effected by condensation.

Quoting the results of observations to show that the temperature in the condenser is practically constant, the Author assumes that 1 kilogramme of the steam to be condensed contains 630 'calories,' equivalent to 1,134 English units of heat by 1 lb. of steam. Adopting English measure, let k = the co-efficient of conducti-

bility of the tubes of the condenser, that is the number of heat units which pass through the sides of the tubes per square foot per hour, for a difference of temperature of 1° Fahr.; t, the temperature of condensation, θ and θ' the temperatures of the condensing water as it enters and as it leaves the condenser; π, the weight of condensing water in pounds expended per hour; and s, the area of condensing surface in square feet, then the following equation is evolved:—

$$k s \pi = \frac{1134 - t}{t - \theta} (k s + \pi) \quad . \quad . \quad . \quad . \quad . \quad (a)$$

the variables k, s, and π being the ordinates of an equilateral hyperbola, of which the equation referred to the asymptotes would be,

$$k s \pi = \left(\frac{1134 - t}{t - \theta}\right)^2,$$

and of which the co-ordinates would be transferred, parallel to themselves, to the apex of one of the branches.

In settling the value of the co-efficient k, the Author quotes the results of experiments made by Thomas and Laureus, by means of a copper worm, in which the value of k, for the square mètre, and for 1° centigrade, amounted to from 4,800 to 5,000 French units; equivalent, for an English square foot, and 1° Fahr., to about 1,000 English units. From observations, however, made on the surface condensers on board the transport ship "Dives," he estimates the value of k = 500 units in English measures (in French measures 2,500 'calories').[1]

The value of the co-efficient is affected by the arrangements for effecting the circulation of the water through the condenser; but it is considered that the co-efficient deduced from the observations on board the "Dives" is sufficiently exact for practical purposes, for condensers arranged, like those of the "Dives," in which the tubes are in three groups, successively traversed by the water. For condensers in which the tubes are divided into only two groups the co-efficient is much less. In the condensers of the "Rochambeau," for example, having the tubes in two groups, the co-efficient scarcely amounted to from 220 to 240 English units (1,100 to 1,200 'calories,' French measure).

The value of the co-efficient is no doubt diminished by the deposits of fatty matter discharged from the cylinders and valves. The co-efficient of 500 units for the "Dives" was deduced from observations when the engines were new. But it is known that in the transatlantic steamers, fitted with surface condensers, the vacuum is diminished by from 1·2 to 2·4 inches (3 to 6 centimètres) during the voyage to America and back. The Author suggests a

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[1] Information bearing on this subject will be found in Péclet's "Traité de la Chaleur," as well as in the Minutes of Proceedings Inst. C.E., vol. xxxv., pp. 55 and 94.

species of trap to be placed at the entrance from the exhaust pipe to the condenser, for the interception of the greasy impurities.

According to the algebraic relations established by the formula (*a*), when the temperature of the condensing water is given, and also the temperature of condensation to be attained, the values of the condensing surface and the quantity of water may be varied indefinitely. The Author represents the relations of the surface and the water graphically, for the cases in which the temperature of the sea-water, θ, is 59° F. (15° C.), that of condensation, t, being successively 95°, 104°, and 113° F. (35°, 40°, 45° C.). The abscissæ of the curves represent the areas of the condensing surfaces, and the ordinates the volumes of water required to produce the steam supplied per hour per square mètre of fire grate, on the assumption that 750 kilogrammes of steam are generated, with good coal, per square mètre of grate per hour (153½ lbs. of steam per square foot of grate). For this an evaporation is assumed of 8·3 lbs. of water per pound of coal (8·3 kilogrammes per kilogramme of coal); 90 kilogrammes of coal being consumed per square mètre per hour (18·5 lbs. per square foot). The data from which the relations of the grate area and the condensing water have been deduced are contained in the annexed Table. From these, in connection with the diagrams, it appears that the sea-water being at 59° F. (15° C.), the condensation must have been effected at about 98½° or 107½° F. (37° or 42° C.).

The diameter of the condensing tubes is generally from 0·76 to 0·8 inch (19 to 20 millimètres); and they are pitched at from 1·2 to 1·4 inch (30 to 35 millimètres). It follows, from the fact of the small variation of these dimensions, that the cubic contents of the condensers bear a ratio to the condensing surface, varying only from 0·1 to 0·131 cubic foot per square foot (0·03 to 0·04 cubic mètre per square mètre), according to the examples given in the Table on page 402.

From this Table it appears also that the weight of the condenser per unit of surface varies from 8½ to 13 lbs. per square foot of surface (41 to 64 kilogrammes per square mètre). Adding about 1·64 lb. per square foot (8 kilogrammes per square mètre) for the water in the tubes, the Author comes to the conclusion that a properly constructed surface condenser should weigh, water included, about 10¼ lbs. per square foot of condensing surface (50 kilogrammes per square mètre).

To show what proportion the weight of the surface condenser bears to the weight of the entire engine, and how this proportion will vary with the quantity of water used, the following calculations have been made, in which the co-efficient k is taken at 500 English units (2,500 'calories,' French measure), the temperature of condensation is assumed to be 104° F. (40° C.), and the condensing water at 59° F. (15° C.). The area of surface per indicated horse-power is added, it being assumed that 17·64 lbs. (8 kilogrammes) of steam only is consumed in a very good engine per horse-power per hour.

TABLE showing the RELATION of CONDENSING WATER to GRATE-AREA in MARINE ENGINES.

Name of Vessel.	Constructor.	Grate-area of the Boilers.	Condensing Surface.		Pump.	Circulation of Water.	
			Total.	Per unit of Grate-area.		Quantity of Water per hour.	
						Total.	Per unit of Grate-area.
		square feet.	square feet.	square feet.		cubic feet.	c. ft. per sq. ft.
Suffren . .	Indret .	637·2	7,750	12·1	O.[1]	72,400	114
Rochambeau .	American	1042·0	10,021	9·6	O.	81,580	78
Infernet, &c. .	Indret .	261·6	3,724	14·2	O.	32,210	123
Résolue . .	Claparède	86·5	1,893	21·9	O.	15,470	179
Dives, Rance .	Indret .	87·2	1,266	14·7	O.	12,070	139
Petrel, Antelope . . .	Creusot .	61·3	1,167	18·9	C.[1]	3,531	58[2]
Hercules . .	Penn .	878·6	20,130	22·7	C.	254,300	289
Martinique .	Elder .	172·2	2,562	14·7	O.	18,640	108
Tourville . .	Forges et Chantiers	950·7	13,520	14·2	C.	152,600	160
City of London	Elder .	170·2	2,754	16·1	O.	18,470	108
Chimborazo .	ditto .	297·3	6,254	21.0	O.	31,430	106
Aracan . .	Denny .	115·2	2,576	22·3	C.	..	..
Indus . . .	ditto .	315·4	4,464	14·2	C.	..	..
Garonne . .	Napier .	279·3	6,207	22·2	O.	..	..

[1] O is the ordinary pump worked by the engine. C is the centrifugal pump worked by a special engine.

[2] The chimney being very low, the consumption of coal was only about 130 to 150 lbs. per square mètre of grate surface, and the steam was proportionately small in quantity.

BULK AND WEIGHT OF SEVERAL SURFACE CONDENSERS. (CASES AND TUBES COMPLETE.)

Name of Vessel.	Arrangement of the Condenser.	Surface.	Volume.		Weight.	
			Total.	Per sq. foot.	Total.	Per square foot.
		sq. ft.	cub. ft.	cub. ft.	lbs.	lbs.
Infernet.	One body, nearly cubical	3,724	359·3	·096	31,520	8·46
Dives .	Two bodies, short tubes	1,266	178·0	·141	16,530	13·06
Résolue .	Elder's system. . .	1,893	226·7	·120	23,810	12·58
Petrel .	One body	1,167	121·1	·104	11,460	9·82
Suffren .	Two bodies, short tubes	7,750	891·4	·115	82,120	10·60

For the respective weights of condensing water per unit of weight of steam of

30, 40, 50, 100 tons,

a condensing surface is required equal to

4·41, 1·94, 1·51, 1·08 square feet,

or, 0·41, 0·18, 0·14, 0·10 square mètre per indicated HP.;

for which the gross weights of condensers will be

45·2, 19·8, 15·4, 11·0 lbs.

or, 20·5, 9, 7, 5 kilogs. per indicated HP. respectively.

As marine engines weigh from 397 to 441 lbs. (180 to 200 kilogrammes) per indicated horse-power, and as the weight of the water of circulation is usually forty times that of the steam, the gross weight of the condenser should not exceed about 5 per cent. of the gross weight of the engine. This percentage is so small that, in the Author's judgment, it is unwise to endeavour to reduce it by increasing the amount of water of circulation, which can only be got by a considerable expenditure of power.

In answering the question, What is the most suitable temperature of condensation? bearing in mind the reduced temperature of the feed water, the extra power required to supply additional condensing water, against the gain of useful work by effecting a better vacuum, and other obvious contingencies, the Author comes to the conclusion that there is no advantage in reducing the temperature of condensation below from 104° to 113° F. (40° to 45° C.).

With regard to the general arrangement of surface condensers, the water is now generally passed through the tubes, the steam being condensed on the outsides. The tubes are usually from 0·64 to 0·8 inch in diameter outside (16 to 20 millimètres), and from 0·04 to 0·08 inch in thickness (1 to 2 millimètres). The length varies from 3 feet 3 inches to 13 feet (1 to 4 mètres), but it is mostly about 6½ feet (2 mètres). The pipes for delivering and discharging the condensing water generally have a sectional area not exceeding from one-sixth to one-seventh of the total sectional area of the tubes; and if the water comes from so small an orifice opposite to the ends of the tubes no doubt only a small number of these will be utilised. To remedy this defect the tubes are sometimes disposed in groups of one to four, most commonly in three groups. The circulating pumps are driven either by the marine engine itself or by a special engine. The Author prefers a special engine driving a centrifugal pump so as to place the quantity of available water under complete control. The total power consumed in effecting this circulation of the water is from fifteen to twenty times that which is consumed in simply communicating velocity to the water. The weight of water supplied per indicated horse-power per hour never exceeds 17·6 cubic feet (500 litres), and its velocity never reaches 13 feet per second (4 mètres), a performance which represents only 0·0015 horse-power; whereas, the average indicated power required to drive the pump amounts to about 2 per cent. of that of the main engine. The results of an

experiment on the resistance of condenser-tubes to the circulation of the water through them are given on the authority of M. Joëssel. He placed three tubes about 4 feet long (1·18 mètre), and 0·72 inch diameter (18 millimètres), as if they constituted the three groups of a condenser; and passed water through them under heads of 3 feet $3\frac{3}{8}$ inches, 4 feet 11 inches, and 6 feet $6\frac{3}{4}$ inches successively (1, $1\frac{1}{2}$, and 2 mètres); first through one tube, then through two tubes, one after the other, and finally through three tubes. The velocities at which the water was discharged in the nine cases are given in the following *résumé* :—

Height of Head.		Velocity of Discharge.					
		One tube.		Two tubes.		Three tubes.	
mètres.	feet.	mètres per second.	feet per second.	mètres per second.	feet per second.	mètre per second.	feet per second.
1·0	3·28	2·02	6·63	1·46	4·70	1·12	3·67
1·5	4·92	2·61	8·56	1·82	5·97	1·32	4·33
2·0	6·56	3·01	9·87	2·02	6·63	1·69	5·54

The results of this Table indicate, in the rapid decline of velocity as the number of tubes is increased, that the division of the condenser tubes into two and three groups, through which the condensing water passes successively, causes a rapid increase of resistance to circulation; and that it would be decidedly better if the condensing water could be efficiently applied directly to all the tubes without dividing them into groups. For the attainment of this object the Author proposes the insertion of a perforated diaphragm facing the ends of the tubes, and parallel to the tube-plate, through which diaphragm the water would be equally supplied direct to all the tubes; and a similar diaphragm for the discharge of the water after having passed through the tubes. By this means, he argues, the condensing surface would be rendered more equally efficient, a less extent of surface would be required, and less power would be needed to circulate the water.

The Paper closes with an inquiry as to the employment of the motion of the vessel itself for producing the current of condensing water through the sides of the vessel.

D. K. C.

Tugboats on the Rhone. By M. Villaret.

(Revue Maritime et Coloniale, Feb. 1874, pp. 620–623, 1 pl.)

The merchandise to be towed from Arles to Lyons is contained in large barges, which offer no particular feature for remark. They are drawn by a steamboat, technically called a 'grappin,'

this being the name of the implement which constitutes the peculiarity of the system. These 'grappin' steamers are 301 feet (92 mètres) long, 23 feet (7 mètres) broad over the hull, and 46 feet (14 mètres) over the paddle-boxes. Their ordinary draught of water is 3 feet (90 centimètres); the paddle-wheels are of the common construction, and are propelled (as is also the 'grappin') by non-condensing engines, working steam at $3\frac{1}{2}$ atmospheres ($3\frac{1}{2}$ atmospheres above zero, or $2\frac{1}{2}$ effective), and of 180 HP. of 75 kilogrammètres per second [= 33,000 foot pounds per minute]. On the paddle-shaft there is a pulley suited to drive a pitched chain. This chain gives motion by a similar pulley to an intermediate shaft, placed at some little distance horizontally from the paddle-shaft, and about 3 feet below it, in a long well-hole in the midships of the vessel, extending from the deck to the bottom, so as to afford free access to the water. A strong wooden horizontal frame, 23 feet (7 mètres) long, is carried by one of its ends on the intermediate shaft, while its outer ends support the 'grappin,' which thus can rise or fall in the well-hole by the frame moving radially round about the intermediate shaft. This shaft carries two other pulleys which, by pitched chains, drive the 'grappin.'

The 'grappin' is a wheel of the same diameter as the paddle-wheels, made of wrought iron and furnished with numerous projecting picks. The 'grappin' and the radial frame, when the boat is coming down stream, are upheld in the well-hole by means of a chain attached to a steam-crab, but on ascending the river with barges in tow, the 'grappin' is lowered through the bottom until its picks act upon the bed of the river, and thus insure the boat moving up stream, the paddle-wheels operating at the same time. There is another steam-crab, which is brought into use under the following circumstances:—

Assume the 'grappin' to be inoperative, in consequence of a hole in the bed of the river or of a rocky bottom, then the barges in tow are cast off and made fast, while the steamboat, free from them, is able, by means of its paddles, to stem the current until it comes to some place where the 'grappin' can again act. The 'grappin' is then lowered, but merely to serve as an anchor, while the steam-crab is put to work to haul up the barges by means of a tow-rope. By this contrivance the barges can be brought from as much as 1,093 yards (1,000 mètres) distance.

The cost of these boats is £24,000 (600,000 francs); the first of them was built at Givors, in 1842, by M. Verpillieux; the second at La Seyne, by Mr. Taylor, in 1848; and five others have been built since. At the present time three only are running. The usual charge for haulage against the stream is 7*s.* (9 francs) per ton for the whole distance from Arles to Lyons [about 200 miles]. From 500 to 600 tons of freight can be towed under ordinary circumstances; but when the current is favourable, as much as 1,000 tons can be successfully dealt with. B.

Theory of the Transmission of Power by Ropes. By H. Resal.

(Comptes-rendus de l'Académie des Sciences, lxxix. Aug. 17, 1874, pp. 421–427.)

The Author points out that the transmission of power by cables or ropes, first used at the Perte du Rhône, is rapidly extending in Switzerland, and is now in operation at Schaffhausen and at Fribourg. As it may be extensively applied to the utilisation of water power in other countries, its theory becomes an object of interest. A complete exposition, however, is very difficult. Only the most usual case is here considered, namely, where the two pulleys carrying the cable are on the same level, and the maximum inclination of the cable to the horizon is not above 30°. The cable is supposed to be in a state of permanent motion. The velocity V is therefore uniform throughout, and all small oscillations, arising from elasticity, &c., are neglected. Let ω be the weight per unit of length of the cable, T the tension at any point $(x\ y)$, and θ the inclination of the tangent to the horizon at that point. Then the equations of equilibrium are—

$$\frac{d\mathrm{T}}{ds} = \omega \sin\theta, \quad \frac{\mathrm{T}}{\rho} = \frac{\omega v^2}{g\rho} + \omega\cos\theta.$$

From these it follows that the curve is a common catenary. Integrating them

$$\mathrm{T} - \frac{\omega v^2}{g} = \frac{m\omega}{\cos\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

$$s = m(\tan\theta + a) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

$$\log \frac{1 + \tan\frac{\theta}{2}}{1 - \tan\frac{\theta}{2}} = \frac{x+b}{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

$$y + c = \frac{m}{\cos\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

Where m, a, b, c are constants, to be determined by the following conditions:—That either span of the cable is a tangent to the circumference of the pulleys at each end, that the sum of the spans plus the arcs of the pulleys touched by the cable is equal to the total length, and that the forces which act on the driving pulley are in equilibrium. By choosing for origin the middle point of the lower or leading span, a and b can be made to vanish. Let Q be the resistance acting upon this span at a tangent to the driving pulley, R the radius of the pulleys, $2\,d$ the distance between their axes, 2λ the length of the cable, ϵ the angle between the vertical and the radius at the point where the lower span touches the pulley.

At this point $\theta = \epsilon$, $x = d + \mathrm{R} \sin \epsilon$; hence equation (3) becomes

$$\log \frac{1 + \tan \frac{\epsilon}{2}}{1 - \tan \frac{\epsilon}{2}} = \frac{d + \mathrm{R} \sin \epsilon}{m}$$

Now ϵ is by supposition a small angle, and R is also small compared with d. Hence as an approximation

$$m \epsilon \left(1 + \frac{1}{6} \epsilon^2\right) = d + \mathrm{R} \epsilon \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Similarly for the other span

$$m' \epsilon' \left(1 + \frac{1}{6} \epsilon'^2\right) = d - \mathrm{R} \epsilon' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

There are also the two following equations:—

$$m \tan \epsilon + m' \tan \epsilon' + \mathrm{R} (\pi + \epsilon' - \epsilon) = \lambda \quad . \quad . \quad . \quad (7).$$

$$\frac{m' \omega}{\cos \epsilon'} - \frac{m \omega}{\cos \epsilon} = \mathrm{Q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

Approximating in these two equations as before, and using equations (5) and (6)—

$$\epsilon^2 + \epsilon'^2 = 6 \left(\frac{\lambda - \pi \mathrm{R}}{d} - 2 \right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

$$\epsilon \left(1 + \frac{1}{3} \epsilon'^2\right) - \epsilon' \left(1 + \frac{1}{3} \epsilon^2\right) = \frac{\mathrm{Q}}{\omega d} \epsilon \epsilon' \quad . \quad . \quad . \quad . \quad (10).$$

or, as a first approximation

$$\epsilon - \epsilon' = \frac{\mathrm{Q}}{\omega d} \epsilon \epsilon' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11).$$

From (9) and (11) the values of ϵ and ϵ' may be determined to a first approximation; then substituting these values in (10) a second approximation may be obtained. The maximum tension will clearly be where the lower span touches the driving pulley, *i.e.*, where $\theta = \epsilon'$. Hence this tension—

$$= \frac{\omega}{g} v^2 + \frac{\omega m'}{\cos \epsilon'}$$

$$= \frac{\omega}{g} v^2 + \omega \frac{(d - \mathrm{R} \epsilon') \left(1 - \frac{1}{6} \epsilon'^2\right)}{\epsilon' \cos \epsilon'} \text{ from equation (6)}$$

$$= \frac{\omega}{g} v^2 + \omega \frac{(d - \mathrm{R} \epsilon') \left(1 + \frac{1}{3} \epsilon'^2\right)}{\epsilon'}$$

This tension should also equal the section of the cable multiplied by the working strain. Hence by substituting for ϵ' its value, as found from (9) and (11), a relation is obtained between the section of the cable and the resistance on the driving pulley; or, in other words, the power transmitted. As, however, the resulting equation is complicated, it is advised that tables should be constructed showing the proper section of cable for different values of the resistance.

W. R. B.

Deep Boring Apparatus in the Haselgebirg. By A. Aigner.

(Oest. Zeitschrift für Berg-u. Hüttenwesen, No. 18, 1874, pp. 164–166.)

Exploration by means of shafts has the advantage of affording visible inspection of the strata. By first making trials with hand-borers the danger of meeting with water may be avoided, although this method is expensive and demands time. The proper speed can only be attained with a free-falling boring instrument; but the nature of the Haselgebirg, and the entire non-appearance of water, led to a modification, which may be of service in carrying out similar undertakings. The boring-rod is fixed to the lever by the usual adjusting screw. The boring-bar has a diameter of $\frac{3}{4}$ foot, and is in convenient lengths screwed together. The lower portion consists of a Kind's boring instrument, as improved by Wlach, and of a cutter weighing 60 lbs., with side blades, cutting to 10 inches diameter, the weight of the lower rod being $3\frac{7}{8}$ cwt. (4 Centner). The results proved it to be well adapted for boring in the Haselgebirg. The side of the bore-hole is not injured by blows from the rod, nor does it require to be supported by tubes, while it is dry, and truly cylindrical, the diameter—10 inches—not being observably diminished.

The results obtained with the apparatus for cleaning out the bore-hole were not so satisfactory. Revolving scoops were employed for the purpose. At a length of 75 feet (12 Klafter) the torsion of the scoop-rod and the excessive friction rendered further proceedings impossible, as the boring-rod made nearly a whole revolution at the turning point before the scoop began to work, and the only remedy thought of was the introduction of water or brine; but this did not answer for various reasons, chiefly because it interfered with the proper examination of the various strata. To continue the dry boring an apparatus was specially designed by Fr. Rettenbacher, which proved successful, for not only was the bore-hole easily kept clean, but the quantity of work done by the borer was increased. This cleaning-out apparatus is of two designs.

In one it consists of an exterior forked vertical frame, to the lower ends of which are attached two cylindrical metal tubes, open at the top and at the bottom, brazed together. At the upper

end of the frame there is a round hole, in which the upper and circular portion of a toothed rack works up and down. Somewhat lower than the middle of the frame a horizontal cross-bar is bolted to it, through which work two spindles, at the upper end of each of which is fitted a bevel wheel, and at their lower ends each has a steel lifting-screw, provided underneath with a cutting edge. These screws revolve at the level of the bottom of the tubes. Just above the cross-bar revolves a horizontal spindle, to each end of which is fixed a spur pinion gearing into the bevel wheel just mentioned. In the middle of the spindle is a spur-wheel, worked by the toothed rack, a catch and pawl arrangement only permitting it to revolve in one direction. The upper circular portion of the toothed rack and forked frame are weighted to 15 lbs., to give the necessary downward pressure to the scooping apparatus. At the upper circular end of the toothed rack, working up and down in the frame as before mentioned, is attached a ring for the rope used for raising and lowering the scoop apparatus.

The second design consists of a similar exterior frame, to the lower ends of which is attached a sheet metal casing open at the top and bottom, while at the top of the frame (as in the first method) a hole permits of the up and down movement of a rod. An interior frame of the same shape as the exterior frame is attached to the rod, fitting closely to, and working within the exterior frame. To the upper end of the rod, above the exterior frame is fixed, as in the first case, an iron ring, to which is fastened the rope for raising and lowering the apparatus. At the lower part of the sheet-metal case are two movable doors or sliding pieces, pressed down by a lead weight fixed to the interior frame. Either of these cleaning-out machines is raised and lowered by a small windlass, having mechanism for changing the position of the jib, and fitted with a break. The boring-rod is furnished with an indicator, as the cleaning-out machine can only be let down on the two vacant or open sides of the boring apparatus.

The manipulation is as follows: Whilst the men working the machinery are resting, the cleaning-out apparatus is got ready to extract the débris. This, in the case of the second design, is done by drawing the interior frame upwards by the ring, forcing at the same time the top of the exterior frame downwards, until the top of the former meets the under edge of the latter, in which position the sheet-metal case is open underneath. The scoop apparatus is then lowered to within 1 foot of the bottom, and allowed to fall freely, upon which the débris enters the casing, the movable feathers close underneath, and the apparatus is raised and emptied.

The same process is gone through in using the first apparatus, only with the difference that instead of the movable feathers or slides, the rotating screw forces the débris upwards.

So far as experience goes this scoop apparatus is available to a depth of 218 feet (35 Klafter). The following table shows the difference of effect between the old plan for a depth of from 0 to 75 feet (0 to 12 Klafter), when its further employment becomes

impossible, and the new system which worked from 75 to 187 feet (12 to 30 Klafter), it being borne in mind that impediments increase with the depth:—

Depth in Vienna Klafter (6·22 ft. English).	8 hour spells.	Men.	Blows.	Height lifted, in Zoll.	Description of ground bored.
		Number.			
0 to 10	1,078	8	25,000	12	Salt, Clay, and Gypsum.
10 „ 20	840	8 and 9	24,000	12	
20 „ 30	750	9 and 10	22,000	12	

It is possible that, with increase of depth, the bending of the boring-rod may render it difficult to introduce the cleaning-out apparatus while the boring-rod is down. The remedy would then be the introduction of light guides; but should this not suffice, the boring-bar must be unscrewed and the boring apparatus lifted, when the scoop apparatus could be used for getting up dry borings from great depths. The first-mentioned apparatus is already in use where, in case of the boring machinery being under repair, the hole is clear from obstructions.

Another scoop apparatus consists of interior and exterior forked frames somewhat similar to the foregoing. To the two forked legs of the exterior frame, and at their lower ends, is fixed a sheet-metal tube open at the top and bottom. A vertical spindle is continued on the top of the interior frame, which works through a hole in the upper part or bow of the exterior one. The fork legs of the interior frame are furnished with teeth gearing into small spur-wheels on a horizontal spindle at about the middle of the apparatus, a crossbar underneath keeping in position a vertical shaft having at its upper end a bevel wheel gearing into a smaller one on the horizontal spindle. The vertical shaft reaches from about the middle of the apparatus to the bottom of the tube, where it carries a screw of steel plate, which rotates and so screws up the borings.

In this case the *modus operandi* is as follows: The scoop is let down the bore-hole until the screw bears on the bottom, when the rope is loosened, and the interior frame sinks down by its own weight until the ring attached to the upper part of its spindle rests on the upper part or bow of the exterior frame, thus stopping the downward movement of the interior frame. The downward movement causes the horizontal spindle to make a couple of revolutions to the left (without effect, owing to a catch and pawl mechanism), and when the scoop rope is lifted the revolutions take place to the right, the vertical shaft revolves twice, causing the screw and tube to enter the borings about 3 inches, and the apparatus is lifted out.

At Ischl by this means the salt formation has been examined

to a depth of 510 feet (82 Klafter) from the surface. The scoop apparatus will recommend itself in all cases where, as in the Haselgebirg, the ground is light, dry, and solid.

J. D. L.

The Burning Coal Mine at Kidder Slope. By MARTIN CORYELL.

(Transactions of American Society of Civil Engineers, September 1874, pp. 147–154.)

The Kidder Slope in the Wyoming Valley was sunk, like other mines in the vicinity, about 300 feet from the out-crop on the 'pitch' or dip, with tramways right and left following the strike of the seam. To increase production, slopes and shafts were opened on adjacent properties, and gangways extended far below the original workings, so that the slope consisted of a pitch or angle of about 20° for 600 feet, next an abrupt angle of 60° or more, and then a flattening down to 30°. An engine, furnaces, and boilers were securely set about 400 feet below the surface in brick and heavy stone masonry laid in mortar, and a brick arch flue, about 3 feet inside diameter and 300 feet long, was constructed to carry the hot air and gases into the old slope of Kidder Colliery. A passage-way alongside the flue allowed a watchman to examine the air currents. For two years or more this work went on most satisfactorily. About December 29th, 1873, the watchman found nothing to report; but two days later, the wooden stack on the surface over the air shaft burned, which, giving direction and intensity to the draft, spread sparks and flames through the old works. To subdue the fire, water from adjacent streams was introduced by pipes, pumps were set to work, and in the mine steam pumps forced water directly on to the fire through passage-ways cut through pillars of coal. The labours of the men seemed successful, but they had left fire smouldering amidst the steam and smoke, which burst forth again in their rear. The rarefied air passing off in furious currents, drew fresh supplies from all parts of the colliery, which fed the fire, and distributed hot air and gases through the mine. To obviate this barricades or 'brattices' were constructed for the protection of the men, and to prevent the air from feeding the fire; when, however, the supply of fresh air was cut off from the fire, the men became helpless. Reservoirs for water were increased in size and number, portable boilers, steam pumps, hose, &c., procured from cities, and men were placed with almost military strictness and discipline, and continuously worked in shifts of eight hours in the mines and of ten hours outside. There were no maps or plans, and everything had to be done at a venture. A roadway was cut, explored, and graded through the old mine; and in a very short time a railroad 3,000 feet long was laid from the surface to the fire for men, mules, and material. Sometimes, when lines of brattices were erected to protect the men, an undiscovered old working would let in the hot air and gases from behind. In several cases it was necessary

to connect sections of work which were cut off or separated by the fire, and air-courses and travelling-ways had to be made where men were exposed to the gases and intense heat. To effect this wooden brattices were projected into chambers filled with hot air and glowing with heat; to maintain them in position and prevent their rapid destruction clay, or the débris of the mine, was cast against them, and the unexposed sides kept dripping with water; these brattices would soon be injured, if not entirely destroyed, but before this more enduring ones could be constructed. Gases and vapours were generated in such quantities that lamps shed but a dim, uncertain light. A suitable portion of the mine was set apart as a hospital, a physician put in charge, and a corps of men kept in readiness at a signal to rescue those overcome by the carbonic acid gas. The freezing of water and streams on the surface caused serious embarrassment, while the heat inside increased greatly; and at the top of the seam the sulphur in the coal and slates boiled out or exuded as a viscous substance, which, as the fire reached it, gave off volumes of sulphurous gas intensely heated. Slates and rocks expanded by the heat, cracks or fissures appeared, large flakes were frequently detached. It was evident that a fall must take place, and one night, 3 acres (2,600,000 cubic feet, or 180,000 tons) subsided at least 10 feet, and spread great alarm.

It was gradually found that concentrated and confined steam gave the best results. An irregular area of about 37 acres was inclosed, and steam at a pressure of 60 lbs. per square inch, generated in thirty-eight boilers (3 feet diameter and 30 feet long), was forced into the mine. The barricades against the fire consisted of brattices, with or without clay, sometimes two 4 feet apart, with clay or dirt in between, a complete and permanent barricade being made of two walls extending from the bottom to the top rock, made of good material laid in mortar, and the space filled in with clay. The temperature of the escaping gas, which exceeded 220° Fahr., was gradually reduced to about 100°, and there was every hope of soon bringing the fire to a termination.

J. D. L.

The Combustion of Petroleum Oils. By M. Barret.

(Annales du Génie Civil, January, March, and April, 1874, 36 pp.)

The chief object of this Paper is to direct attention to the dangers incidental to the transport and storing of petroleum, and to the means of extinguishing fire when it takes place. In commerce, petroleum is recognised as of two kinds: one is light, of a greenish-brown colour, varying in density from 0·800 to 0·815; the other is heavy, of a deeper colour, and of a density varying from 0·840 to 0·900. As petroleum is not commonly fit to be used in its crude state, fractional distillation is resorted to. The products of such distillation are:—1. The essential oil of petroleum, colourless

and extremely fluid. It volatilises quickly, and produces very inflammable vapour. The density is from 0·700 to 0·750. 2. Photogene, or burning oil, usually of a yellow colour; it gives off inflammable vapour at 98°·6 F. (37° C.); specific gravity from 0·800 to 0·815. 3. Lubricating oil, of a density varying from 0·840 to 0·900. 4. Paraffin and tar, employed for the same purposes as asphalte.

Petroleum in the crude state, or the essential oil of petroleum, spread in a sheet, either on water or on the ground, and exposed to the open air, takes fire at a temperature above 32° F. on the application of a lighted match. The presence of flame, however, is necessary for its ignition at a temperature below 68° F. (20° C.). A lump of coal at a cherry red, or of iron at a dull red heat equal to from 1,112° to 1,292° F. (600° to 700° C.), plunged into the liquid does not ignite it. When placed in an open vessel and suddenly raised to a temperature of from 572° to 662° F. (300° to 350° C.) by the immersion of a piece of red-hot iron, these liquids give off intensely white vapours which explode like gunpowder by contact with flame. Two barrels were filled, one with crude oil, the other with the essential oil, to within 1 inch (2 to 3 centimètres) of the bung-hole; on setting fire to the contents, they burned with wavering flames about 3 inches high (6 to 7 centimètres) without any explosion. Refined burning oil is not considered up to standard unless it requires for inflaming a temperature, at the lowest, of 98°·6 F. (37° C.); that is to say, the temperature of the small portion in contact with the flame. Some imagine, however, that it is not the oil in the liquid state which burns, but its vapours. This conclusion is negatived by a lighted night-light floating on the surface of refined oil at a low temperature; a few seconds afterwards, flame is communicated to the oil immediately surrounding the night-light, and extends gradually over the whole surface of the oil. M. Pelzer's experiments, on the qualities of petroleum, show the relation of density to the temperature at which it inflames. Annexed are the densities for various temperatures :—

Density.	Temperature of Inflammation. ° F.	° C.
0·685	− 5·8 or	− 21
0·700	− 2·2 ,,	− 19
0·740	+ 59·0 ,,	+ 15
0·750	62·6 ,,	17
0.760	95 ,,	35
0·775	113 ,,	45
0·783	122 ,,	50
0·792	167 ,,	75
0·805	194 ,,	90
0·822	230 ,,	110
0·802 (crude petroleum)	59 ,,	15

The Author shows that as there cannot be explosion without a space for vapour (mingled with air) in the recipients above the petroleum, it would render the storage of petroleum safe if it were kept in vessels immersed overhead in water, communication being

made between the water and the oil vessel at the bottom of the latter. The petroleum being drawn off from the top, the water would flow in below and thus always keep the petroleum close up against the top of the containing vessel, and prevent the possibility of an accumulation of vapour.

A stratum of crude petroleum 3·6 inches thick (9 centimètres), weighing 176 lbs. (80 kilogrammes), was kept at rest on the surface of the sea, within a floating inclosure 40 inches square (1 mètre) and 8 inches high (0·2 mètre). The weather being calm, and the temperature of the air 59° F. (15° C.), this quantity was burned in thirty-five minutes, and raised a column of flame 8 feet 2 inches high (2·5 mètres). Combustion thus proceeded at the rate of 5 lbs. per minute (2·28 kilogrammes), consuming a thickness of 0·108 inch (2·7 millimètres) in the same time. When the layer of petroleum was reduced by combustion to a thickness of from 0·20 to 0·24 inch (5 to 6 millimètres), the sea-water commenced to boil, the agitation caused by which redoubled the energy of the combustion, and raised the flame to a height of 19 feet 8 inches (6 mètres). The residue of the combustion consisted of a sheet of black fatty matter 0·08 inch (2 millimètres) thick.

It is remarked that the slightest agitation of the surface of the oil very much augments the development of flame. A small piece of wood thrown into burning petroleum on rising liberates vapour and causes an explosion like that of gunpowder. The Author describes in detail the process of burning experimentally barrels of petroleum under varying circumstances. He then points out how essential it is for safety that petroleum in warehouses should be below the ground level, and that ships in port should be surrounded by floating inclosures, so that in both instances the oil, in the event of a fire, may be prevented from spreading. He next proceeds to the consideration of the volatility of petroleum and its products, to ascertain which each kind of petroleum was exposed to the open air in glass vessels exactly gauged, presenting an evaporative surface of 4·65 square inches (30 square centimètres), with a volume of 12·8 cubic inches (210 cubic centimètres) forming a column 2·76 inches high (7 centimètres). From the observed depressions of level caused by evaporation the loss per square yard of surface per twenty-four hours was deduced as follows:—

0·64	gallons	per	square	yard	(3·5	litres	per	square mètre) refined petroleum.
1·66	,,	,,	,,	(9	,,	,,	,,	) crude ,,
3·31	,,	,,	,,	(18	,,	,,	,,	) alcohol.
7·18	,,	,,	,,	(39	,,	,,	,,	) essential oil.

The manner in which fire by petroleum may be prevented in warehouses and on quays, and the best means for securing its safe storage, may be briefly stated as follows:—

(1.) Storing barrels or cases in warehouses of one storey only, built of incombustible materials.

(2.) Transferring the oil into metallic tanks.

(3.) Making a large tank in masonry, filling it with water, and plunging into it, mouth downward, a vessel, like a gas-holder, containing the petroleum, which is to float on the water within the inverted vessel.

(4.) Attaching weights to the ordinary barrels and sinking them in water.

The Author points out that if a vessel laden with petroleum takes fire in a crowded port, it is worse than useless, so far as the other vessels are concerned, to scuttle her, because the water rushing in displaces the petroleum, and thus causes it to float about over the surface of the water instead of being confined to the burning ship.

The Paper concludes with two tables, one of which shows the relative proportion of the various products obtained by fractional distillation from different petroleums, and is given below *in extenso*.

The other table, based on the experiments of M. Henri Saint-Clair Deville, gives the specific gravities, the co-efficient of dilatation and the weight of water that can be evaporated by each of forty-one different mineral oils. The specific gravity varies from 0·786 for petroleum of Parma to 1·044 for the heavy oil of the Parisian Gas Company. The co-efficient of dilatation ranges from 0·000641 in the case of petroleum of Hanover (Wilze) to 0·001 in the case

Products of Distillation.	Oil from Pennsylvania (density 0·802).	Oil from Canada (density 0·835).	Oil from United States, provinces unknown (density 0·820).
Essence of petroleum ($d_1 = 0·735$)	14·7	12·5	4·3
Lighting oils ($d = 0·820$)	41·0	35·8	44·2
Lubricating oils . . .	39·4	43·7	45·7
Paraffin.	2·0	3·0	2·7
Residue.	2·1	3·2	2·2
Loss.	0·8	1·8	0·9
Totals	100·0	100·0	100·0

of the Parma petroleum (before mentioned) and of Canada West; while the power of evaporating water lies between 12·240 times the weight of the oil for the crude petroleum of the schists of Vagnas (Ardèche) to 15·364 times the weight of the combustible for the oil of Schwabwiller (Bas-Rhin).

D. K. C.

Respective Merits of Blast-furnace or Cupola Castings.

By A. Ledebur.

(Berg-und Hüttenmännische Zeitung, No. 2, 1874.)

It being often specified in orders for gas and water tubes that the casting be made from the cupola, and not direct from the blast furnace, the Author has been led to investigate the inherent changes, produced by remelting pig iron in a cupola, that make it denser and stronger than when flowing directly from the blast furnace. No doubt there is an oxidising effect[1] great in proportion to the height above the tuyeres at which the iron melts; greater, therefore, in the cold-blast furnace, and in the old form of cupola, worked with small blow-pipes and a high pressure of blast, than in the more recent forms. The best of all is Krigar's cupola, in which the blast, passing through wide openings partly filled with red-hot coke, has its free oxygen taken up and neutralised before coming in contact with the iron. The value of this oxidising effect of melting in cupolas depends upon the purpose for which the casting is intended. Iron, carbon, silicon, in a less degree sulphur, and in a still less degree phosphorus, are burnt out, and a less carbonised, purer, denser iron is the result. For most purposes an iron is wanted soft enough to work, but strong and uniform in texture, and free from hard lumps, formed of an agglomeration of crystalline grains, with pure carbon, much of it as graphite, very free from silicon, sulphur, and phosphorus. Too much graphite gives the iron a looser texture and renders it weak, as does also silicon; too little, makes it liable to break up under the tool. Sulphur renders it sluggish when molten, and honeycombed when cold, from the fact of sulphur gases being given off. Phosphorus, though making it liquid when molten, causes it to be brittle when cold, and tends to make white iron. Pig such as No. 1, always rich in silicon, and often containing much sulphur, is improved by one, two, and even three remeltings. But less graphitic iron, such as No. 3, coke pig and all charcoal pigs which contain the right proportion of graphite, are not improved by it; charcoal pig, in fact, cannot be remelted alone, though it improves No. 1 when remelted with it.

The absorption of carbon is directly proportional to the time the iron remains unmolten after having been reduced from the ores. The proportion of combined to uncombined carbon is a function of the temperature of the smelting zone, or rather of the degree to which the iron is superheated. A high temperature works powerfully in producing graphitic iron, and this in two ways; directly, by changing the already formed carburet (Fe_4 C) into one less

[1] This oxidising effect of the blast is relatively much less in the blast furnace, because there the iron is protected not only by the slags, but also by the greater proportion of fuel to iron; and the blast being hot, the active oxygen is more rapidly taken up, and its effect neutralised by the carbon.

soluble; and indirectly, by reducing and dissolving foreign substances, such as silicon, which prevent the intimate chemical combination between iron and carbon. The uncombined carbon of the first sort is easily changed into combined by remelting at a low heat and sudden cooling. But the uncombined carbon of the second sort, such as Scotch foundry pig, remains grey even when rapidly cooled. In general it may be assumed that ores easy to reduce and smelt with a liquid slag yield, when the temperature of the smelting zone is low, a white highly-carbonised pig, and when the temperature of this zone is higher, a grey or mottled pig. With ores easy to reduce, but hard to smelt, the remelting pig is grey with little combined carbon, such as No. 2, made up chiefly of crystalline grains of pure iron. Ores hard to reduce, but easy to smelt, always yield a white pig iron poor in carbon.

The first group includes spathic ores and spherosiderites, which are the best for getting highly-carbonised white irons. Between the first and second would come brown hæmatites of recent geological formation, such as bog ores, minettes, and bean ores (the last two from Luxembourg), which are suitable for either grey or white iron. To obtain grey irons from these, a high heat in the hearth, got by a highly heated blast, is required, and the slag should be a basic refractory one. The second group is represented by nearly all the red hæmatites, as well as the brown hæmatites from the older formation. The charcoal irons of the Harz and Nassau, and the Cumberland pigs, are good examples of the produce of these last. Magnetic ores belong principally to the third group, from which most Swedish pig is produced. The last group is made up almost unexceptionally of forge and finery cinders. When grey iron is to be produced only a small percentage of these can be used.

As resistance to breaking may generally be taken as the chief requisite in cast iron, the Author gives some tables of breaking strains for comparison. The experiments were made on bars, cast in a half-upright mould, 0·99 inch (25 millimètres) square, laid on supports 31·5 inches (0·8 mètre) apart, the load being applied at the centre. They represent the mean of several hundred trials.

	kgrs.	lbs.
1. Charcoal iron direct from the blast furnace, from a mixture of magnetic and hydrated brown hæmatite peroxide, broke at.	426	1,137
2. Charcoal iron direct, from red and brown hæmatites and a little magnetic ore	436	1,164
3. The same iron melted with charcoal in an old form of cupola .	425	1,134
4. The same iron melted with coke in an old form of cupola .	375	1,001
5. The same mixed with Scotch iron and melted with coke .	398	1,062
6. Charcoal iron from bog ores.	387	1,033
7. The same melted with coke in an Irish cupola . . .	360	961
8. The same mixed with equal parts of English pig (Clarence) and melted like the last	425	1,134
9. Scotch iron, Langloane No. 1, melted once with coke . .	400	1,068
10. Scotch iron, Langloane No. 1, mixed with an equal part of white manganiferous iron, and melted with coke at a very high heat	525	1,401

The Author deduces for these that it is sufficient, in giving orders, to specify the resistance to rupture, and that in many cases castings direct from the furnace may be actually better than those from a cupola.

F. W.

On the Size of Blast-furnace Charges.

(Berg-und Hüttenmännische Zeitung, No. 7, 1874.)

G. Ringel has shown by statistics, that small charges are better than large ones. Other conditions, including that of the production of iron, being equal, a small charge will be at least three hours longer in the furnace than a large one; it remains so much longer exposed to the furnace gases, and the charges follow each other past the tuyeres more than twice as quickly; by which means the temperature in the carbonising and reduction zones is reduced, while the charges reach the zone of smelting in a better state of preparation.

Small charges have, moreover, the following advantages:—

(*a*) The layers of ore being thinner allow a more intense action of the gases.

(*b*) The more rapid alternation of the charges prevents too high a temperature in the zone of preparation, and lessens the danger of scaffolding.

(*c*) The fuel is more equally distributed, and by presenting a larger surface to the incoming blast is more thoroughly utilised.

(*d*) The better intermixture of the fuel with the batch allows the injurious ingredients of the former to be more quickly absorbed by such ingredients as are added to neutralise them.

(*e*) The temperatures in the zones above the smelting zone being lower, and the iron therefore more completely reduced and more thoroughly carbonised, the injurious influence of the sulphur given off by the fuel is lessened.

(*f*) The temperature above the boshes being lower, opposes the reduction of silicon.

A great error is made in preferring large to small charges, especially for the fuel, as the temperature of the furnace is too much raised by so doing. Practice has shown that 17 to 20 cwt. is a good fuel charge, and far preferable to one of twice that size. As a basis for calculating the charges of fuel, it is often laid down that it should be sufficient to form a layer over the broadest section of the furnace, which should be thick enough (according to some metallurgists, 4 inches and more) to prevent the next ore charge from getting through; but this is an unsafe rule to act upon, as one component of the calculation, the density of the coke, is very variable.

The Author, after restating the advantages of small charges, adds that lime also has the effect of more thoroughly carbonising the iron, and that by using small charges and lime, the sulphur from the fuel can be kept out of the pig.

F. W.

Inquiries into the Texture of Iron. By M. Janoyer.

(Annales des Mines, No. 1, 1874, pp. 80–109.)

The Author starts with the assumption, that the granular texture is the only arrangement of particles inherent in the metal, and adduces arguments and experiments to confirm the statement. The different classes of iron, such as granulated and fibrous, or iron into the texture of which both these elements enter, are the results of an imperfect or defective process of manufacture, not admitting of that perfect welding or amalgamation of particles, which alone constitutes the true condition of the metal. All descriptions of wrought iron may, therefore, be classed under the two general heads of granulated, or iron perfectly welded throughout the entire mass, and fibrous, in which these conditions do not obtain.

Iron, manufactured with wood fuel, when it is very pure and homogeneous, has always a granulated texture. Without denying the influence of the hammer, to which some attribute the texture in question, it is due essentially to the high temperature, which promotes the repulsion of the scoriæ and the perfect welding of the entire mass. In order to prove that high temperature is indispensable to the production of granular iron, it is sufficient for the puddler, engaged in making blooms for iron of that description, to lower the temperature of the furnace, to roll the bloom about in the scoriæ, and to place it in that condition under the hammer. The iron produced will be altogether of a fibrous character. Nevertheless, in this operation the puddling process has suffered no alteration, and yet the granular iron has become fibrous. The lowering of the temperature, which favoured an imperfect welding, and the interposition of scoriæ are the only agents accountable for the change in the texture of the metal. As the transformation of granular into fibrous iron is produced by lowering the temperature, at a certain stage in the manufacture, the reverse of the operation changes fibrous into granular iron. It is merely necessary to raise the temperature sufficiently to effect the welding. Thus iron can be manufactured of either character, as may be required: and a bar may present at one extremity a texture of the one nature, and of the other at the opposite end.

What has been already stated relates to the production of raw iron; it remains to be seen how the different operations of forging, rolling, and converting it into wrought iron, affect the texture. If several bars of granular iron be made into a pile, reheated to a white heat, and then passed through the rolls, the rolled bar will be also of a granular texture, provided always, when it leaves the last groove, the temperature is sufficiently high to maintain the welding complete. If, on the other hand, the bar leaves the rolls at a simple red heat, the texture will be fibrous, because the amalgamation of the particles is incomplete. The bar being drawn out in too cold a condition for the particles

to weld together, they slide upon one another, the tissue is lengthened, and the fibrous condition results. Whenever a slight indication of fibres is seen in large granular bars, it will be found to occur at the junction of the different pieces forming the pile, where, owing to the interposition of scoriæ, the welding has not been perfect.

The microscope shows that while in granular iron, the degree of homogeneity is considerable, the contrary is the case with that of a fibrous nature. Moreover, it confirms the statements respecting the purity and density of granular iron, and at the same time demonstrates the cellular and imperfectly amalgamated condition of the fibrous metal. The microscope also shows the want of uniformity of texture in mixed irons, and the presence of foreign bodies in iron made with coal, after the English method. The fineness of the grain, considered absolutely, is not due to the presence of carbon, and, consequently, does not necessarily indicate a steely character. Swedish irons are examples of this; for, although of a decidedly steely nature, they frequently are very large grained. The fine grain merely insures iron of superior quality as regards its tenacity. The microscope leaves no doubt whether coal or wood has been employed. Fibrous iron made with wood fuel always presents a bright section, never the dull, black appearance belonging to that made with coal.

To prove the evil effects of imperfect welding, an experiment was made in which 33 lbs. of old iron were added to a charge, in the hope that it would become incorporated with the whole mass made from the pig. The old iron became oxidised, and formed a scoria which remained in the metal. When old iron was not added in this manner, the quality was excellent. Granular iron being more readily welded than fibrous, its density is greater in the proportion of 7·791 to 7·751. Other figures give 7·78 and 7·60. For the same reason, granular iron resists strains of tension and compression better than the other, but it is weaker with regard to flexure, although possessing greater elasticity than fibrous iron. With respect to malleability and ductility, the fibrous or non-welded iron is more malleable, but less ductile than the granular. The metalloids sulphur and phosphorus play opposite parts in their influence upon iron. The former prevents the perfect welding, and, owing to the formation of scoriæ, the fibres are short and black. On the other hand, phosphorus assists this amalgamation or welding of the particles and produces a granular iron. From this it is maintained that iron has but one normal condition of particles, the granular, which is based upon the essential property of welding or amalgamation. All other textures are simply the result of a defective and imperfect welding in the process of manufacture.

C. T.

On the Mechanical Properties of Gun-metal. By M. Tresca.

(Annales du Conservatoire des Arts et Métiers, No. 38, pp. 324–334.)

It was found during the siege of Paris that specimens of gun-metal, when tested by tension, gave different results. This led to careful experiments on three varieties of bronzes, of which the composition was as follows :—

——	Ordinary Bronze of Bourges.	Phosphoric Bronze of Bourges.	Laveissière Bronze.
	(B.)	(P.)	(L.)
Copper . .	89·87	90·60	89·47
Tin . . .	9·45	8·82	9·78
Zinc . . .	0·31	0·27	0·66
Lead . . .	0·37	0·31	0·09
Total. .	100·00	100·00	100·00

Rectangular bars, 2 inches by 1 inch (0·05 mètre by 0·025 mètre) in section, were tested by flexion, and bars 1 inch (0·025 mètre) square, and round bars $\frac{2}{5}$ inch (0·012 mètre) in diameter by tension.

The mean results of the tests are as follows, the units of length and of section being 1 mètre (3·28 feet) and 1 square mètre respectively.

Modulus of elasticity.	Weight at limit of elasticity.	Elongation at limit.	Breaking weight.	Ultimate elongation.
		B.		
kilogrammes. 7,589,000,000	kilogrammes. 8,961,000	mètre. ·001182	kilogrammes. 16,715,000	mètre. ·0365
lbs. (10,770,000)	lbs. (12,700)	ft. (·0039)	lbs. (23,100)	ft. (·12)
		P.		
kilogrammes. 8,250,000,000	kilogrammes. 8,667,000	mètre. ·001222	kilogrammes. 21,827,000	mètre. ·047
lbs. (11,734,000)	lbs. (12,300)	ft. (·004)	lbs. (31,000)	ft. (·154)
		L.		
kilogrammes. 9,061,000,000	kilogrammes. 11,210,000	mètre. ·001125	kilogrammes. 26,270,000	mètre. ·177
lbs. (12,887,000)	lbs. (15,900)	ft. (·0037)	lbs. (37,300)	ft. (·58)

The English weights are referred to 1 square inch as the unit of section. B in its fractured section had a metallic lustre and

numerous grains of tin; P had a dull appearance, grained surface, and uniform texture; L had a metallic lustre, grained surface, and very uniform texture. It appears from the above table that the moduli of elasticity of B, P, and L are in the ratios of 1·00, 1·09, and 1·20, and that the limit of elasticity of L exceeds that of B and P by one-fourth, the elongation at the limit being the same for all.

The mechanical work expended is represented by the products of the weights into the corresponding elongations; and in the case of rupture the following proportions exist:

	Breaking weight.	Elongation.	Mechanical work.
B	1·00	1·00	1·00
P	1·31	1·29	1·97
L	1·57	4·85	7·45

so that $7\frac{1}{2}$ times more mechanical work must be expended to break a bar of L than is required for B. The superiority of the Laveissière bronze in every respect over the other two is evident; and the phosphoric bronze is shown to be better than the ordinary bronze of Bourges. L. V. H.

Experimental and Geometrical Investigation of Internal Ballistics. By General Morin.

(Annales du Conservatoire des Arts et Métiers, No. 38, pp. 304–323, 1 pl.)

While acknowledging the efforts of Hutton, and while giving due credit to the elegant experiments of Rumford, it must be admitted that Piobert, following the wise precept of Bacon to base his reasoning on experiment, was the first to establish a mathematical theory of the expansive forces of explosives in fire-arms, and of the laws of motion communicated to the projectiles, which laws are called internal ballistics. In 1846-47 the relative merits and behaviour of gunpowder and gun-cotton were investigated, by determining the velocities imparted to bullets weighing 444 grains (28·8 grammes), and having a diameter of $\frac{2}{3}$ inch (17 millimètres), fired with charges of 123 grains (8 grammes) of powder, or 44 grains (2·86 grammes) of gun-cotton, in gun-barrels of ten different lengths, varying from 4 calibres to 64 calibres. The results of these experiments may be represented by curves, the abscissæ being the spaces traversed by the projectile, drawn full size, and the ordinates, half its 'vires vivæ,' drawn to a suitable scale on section paper. The inclination of tangents to the curve thus described, where the ordinate is $\frac{1}{2}\frac{W}{g}V^2$ and the abscissa s, is $\frac{W}{g}\frac{V\,dV}{ds} = \frac{W\,dV}{g\,dt}$ which gives the motive force imparted to the projectile; or the resultant of the expansive force, the resistance to alteration of shape, friction, and displacement of air. By marking off abscissæ at definite intervals, drawing ordinates to meet the curve, and

assuming the portion of the curve intercepted between each ordinate to be a straight line, the curve becomes a polygon, the sides of which correspond to the inclinations of the required tangents. These are easily calculated, and the values of the forces imparted to the projectile at any part of its passage through the barrel are in this manner readily found. The results thus arrived at approach much nearer to the truth than do those obtained by M. Pothier's graphic method of drawing normals, applied by him in working out the results of certain experiments conducted with cannon in 1869. The conversion of the curve into a polygon implies that the force exerted on the projectile may, without great error, be considered constant in the space between each ordinate, and that the motion of the projectile may be taken to vary uniformly between these points. On this assumption the following relations are obtained between s, the space traversed; t, the time of transit; V, the velocity acquired; and F, the force:—

$$V_1^2 = 2\frac{F_1 g}{W} s_1 \quad V_2^2 = V_1^2 + 2\frac{F_2 g}{W} s_2 \quad V_3^2 = V_2^2 + 2\frac{F_3 g}{W} s_3$$

$$s_1 = \tfrac{1}{2}\frac{F_1 g}{W} t_1^2 \quad s_2 = V_1 t_2 + \tfrac{1}{2}\frac{F_2 g}{W} t_2^2 \quad s_3 = V_2 t_3 + \tfrac{1}{2}\frac{F_3 g}{W} t_3^2.$$

These formulæ show the total time occupied by the standard bullet in traversing a barrel $3\frac{1}{4}$ feet (1 mètre) long to be, with the standard charge of gunpowder, $\frac{1}{239}$ second, and, with gun-cotton, $\frac{1}{310}$ second. They also show that the velocity acquired at the muzzle should be 1,247 feet (380 mètres) with gunpowder, and 1,260 feet (384 mètres) with gun-cotton, the actual velocity being 1,234 feet (376 mètres) for both. The maximum motive force, exerted by the explosive, is to the mean motive force capable of producing the same velocity, as 2·39 to 1 with gunpowder, and 6·02 to 1 with gun-cotton. These investigations also demonstrate that the velocity imparted by gun-cotton to the projectile at the commencement of its course is greater than that derived from gunpowder, but that the difference in time in passing over equal spaces becomes less as the projectile advances, and just before leaving the barrel the times are the same for each. The velocity imparted to a projectile by gunpowder increases continuously, though more slowly, as it advances; but with gun-cotton the velocity actually decreases before it leaves the barrel, owing to the condensation of the water, which is one of the products of the combustion.

L. V. H.

Experimental Researches on Explosive Substances.

By MM. Roux and Sarrau.

(Comptes-rendus de l'Académie des Sciences, Oct. 5, 1874, pp. 757–760.)

It had been shown in a former communication that dynamite might be exploded by two methods. Simple explosion is caused by

the ordinary ignition of the substance; detonation—by the percussion of a strong priming of fulminate of mercury. By these two kinds of explosion very different pressures are produced, and the Authors have endeavoured to measure the relative intensities of these pressures, by the quantities of each explosive substance respectively required to rupture bomb-shells identical in form and dimension. They have shown, further, from recent experiments, that this property of double explosiveness belongs to the greater number of other explosives besides dynamite. The charge of gunpowder, necessary to produce rupture, was 200·62 grains (13 grammes)—by simple explosion. The ratio of 13 grammes to the rupturing charge of another substance is a measure of the force of the substance, the force of gunpowder by simple explosion being taken as 1. The subjoined Table contains the explosive force, thus experimentally obtained, of various substances, together with the proportion of permanent gases produced by simple explosion, in percentages of the weights of the substances, and the quantity of heat disengaged by 1 kilogramme and 1 lb. of the substance, in French and English units respectively. It is shown that the simple explosive force of gunpowder is more than quadrupled by detonation; that the simple explosive force of a substance is proportional to the product of the weight of gases disengaged by the heat; and that the detonating forces, for six of the substances, are nearly proportional to the heat disengaged.

Results of Experiments on Explosive Substances.

Substance exploded.	Explosive force, that of Gunpowder, by simple explosion = 1.		Relative weight of gases.	Heat disengaged by			
				1 Kilogramme, French Measure.		1 lb., English measure.	
	2nd order.	1st order.		2nd order.	1st order.	2nd order.	1st order.
	ratio.	ratio.	per cent.	units.	units.	units.	units.
Fulminate of mercury	..	9·28	..	..	752	..	1,354
Gunpowder	1·00	4·34	41·4	731	732	1,316	1,318
Nitro-glycerine	4·80	10·13	80·0	1,720	1,777	3,097	3,200
Pyroxyle	3·00	6·46	85·0	1,056	1,060	1,902	1,909
Picric acid	2·04	5·50	89·2	828	868	1,491	1,563
Picrate of potass	1·82	5·31	74·0	787	852	1,417	1,534
Ditto baryta	1·71	5·50	71·9	671	705	1,208	1,270
Ditto strontium	1·35	4·51	62·4	637	745	1,147	1,342
Ditto lead	1·55	5·94	66·8	555	663	999	1,194

D. K. C.

On the Employment of Electro-coppered Cast-iron Cylinders for Printing on Stuffs. By Th. Schlumberger.

(Bulletin de la Société Industrielle de Mulhouse, March 1874, pp. 116–120.)

During the last thirty years, repeated attempts have been made in England to replace the solid copper and brass cylinders used in printing-mills by cylinders of cast iron, covered with copper by galvanic deposit. These attempts have not been attended with the success that was anticipated, and the system has fallen into comparative disuse.

In 1871, M. Théodore Schlumberger presented to the "Société Industrielle de Mulhouse" a Note on the Employment of Cast-iron Coppered Cylinders, and in March last M. Gustave Schæffer reported to the society, which had offered a prize for the best essay on the subject, the progress made up to that time.

Neither the Note of M. Schlumberger nor the Report of M. Schæffer are encouraging. The advantages are sufficiently great to induce perseverance; but the serious difficultes lead to the conclusion, that further experiments should be undertaken from a new starting-point. The copper and brass cylinders employed, in a printing-mill represent a large capital. A new roller weighs between 1 cwt. and 2 cwt., the metal costing 2*s.* to 2*s.* 6*d.* per lb., and it can only be employed until, having been successively turned off and re-engraved, its weight is reduced to about ½ cwt. Each re-engraving lessens the weight by about 5 lbs, and the diameter by somewhat more than the depth of the previous engraving. Sometimes, when adapting a roller to a given pattern, or pairing it with another to a given design, much more than this has to be turned to waste. Could cast iron be used as the foundation of these rollers, the saving in capital sunk in these machines would be obviously great. The raw metal would cost less than 1½*d.* per lb., and, when prepared to receive the copper coating, little more than 3½*d.* per lb.

Since 1864 M. Louis Huguenin has coppered a number of rollers, which have been engraved five or six times without any inconvenience. M. Schlumberger asserts that a positive advantage was gained each time the rollers were put into the coppering vats, because the imperfections on the surface of the copper disappeared. He estimates the cost of a cast-iron roller of ordinary dimensions at £4, and the cost of each re-coppering at from 8*s.* to 16*s.*—a price which is capable of reduction.

The difficulties, on the other hand, are serious. In the first place, the saving of cost is less than appears from the estimate of the saving of so many pounds of copper, from the fact that the electrotype copper costs at least five or six times as much as the commercial copper ordinarily used. Next, the adherence between the cast iron and the copper is not sufficient to prevent the latter from being injured under great pressure, and sometimes becom-

ing laminated and loosened from the iron. Lastly, a cast-iron coppered roller is more difficult to repair than a solid copper or brass one. When one of the latter gets injured the place is plugged, or the surface burnished up and engraved; with a cast-iron cylinder, however, these processes are difficult, for plugging is attended with the danger of breaking through the coat and leaving the iron exposed, by which the colours or the mordants are altered, while burnishing causes the copper to dilate, and destroys its adherence to the iron.

The process in these experiments was as follows:—

After the surface has been turned up true in the lathe, the cast-iron roller is cleansed of grease by a strong alkaline solution, and washed with an abundance of water, all traces of oxide being removed with a fine file. When this is accomplished, the metallic surface is brilliant, and great care must be taken to prevent the moisture of the breath or of the fingers from coming in contact with it. The cleansed and polished roller is then plunged in an alkaline copper bath, and left during twenty-four hours under the current of five or six elements until the whole surface of the cast iron is covered with a thin but well-adhering skin of copper. This alkaline bath may be composed as follows:—In 12 parts of water dissolve 1 part of sulphate of copper. In 16 parts of water dissolve cyanide of potassium, 3; carbonate of soda, 4; sulphate of soda, 2 parts. The two solutions are mixed after the salts are completely dissolved. Another alkaline bath is composed thus:—Water, 10; ammonia, 3; acetate of copper, 2. Water, 16; cyanide of potassium, 3; of soda, 4; sulphate of soda, 2.

After removal from the alkaline bath, the roller is washed and rubbed with rottenstone. If the iron in any place shows through the film of copper, the roller is returned to the bath until the entire surface is covered. This first coat should be perfect, but as thin as possible. When that result is attained, the roller is well brushed, washed, and rinsed in slightly acidulated water. It is then plunged quickly into an acid bath of sulphate of copper, in which it is left until the deposit of copper is sufficiently thick, being turned partly round each day so as to insure an even deposit. With the current of four elements, and at a moderate temperature, three to four weeks are required to effect a deposit of $\frac{3}{4}$ of a millimètre in thickness.

The strength of the solution of sulphate of copper is represented by 20° Beaumé, in which 1 quart of sulphuric acid is added to every 300 quarts of solution, to render the bath more conducting and to assist the dissolution of the scrap copper thrown in to keep up the strength of the bath.

R. S.

Cultivation of the Sugar-cane in Spain. By M. Grand.

(Mémoires de la Société des Ingenieurs Civils, April 1874, pp. 266–269.)

The cultivation of the sugar-cane in the 37th degree of north latitude would appear very remarkable to any one unacquainted with the peculiar climatic conditions which render it practicable. That portion of the coast of Andalusia which permits of the growth of the sugar-cane is comprised between the 36th and the 37th degrees of north latitude. At a certain distance from the sea a chain of mountains runs parallel to the coast and forms a shelter from the north winds. The evil effects of a short frost, which occurs once in seven or eight years, are avoided by cutting the cane somewhat earlier in the season than usual. The geographical position of this part of Andalusia enables it to command a great amount of solar heat. As, in addition to a warm climate, a certain degree of humidity is requisite for the growth of the cane, artificial irrigation is resorted to when the natural sources fail. Of the three varieties of canes, that known as American is the best, and is fast superseding the others in all the new plantations. From seven to eight years constitute the productive life of the sugar-cane. The planting is performed by cutting slips from sound canes of the previous year and placing them horizontally end to end in two rows at the bottom of broad furrows. This operation takes place in May. In October the cane turns yellow, in the following February it arrives at maturity, and it is harvested in the three succeeding months.

Irrigation is indispensable during the dry season, which lasts for three or four months, and as nearly 1,000,000 gallons of water are required for each acre of land, the construction of reservoirs is frequently necessary. The sugar-cane is a very exhausting crop, so that proper manuring of the soil is a subject of great importance. Farm-yard manure, mixed with the refuse of the last crop, is used when the harvest is annual, but when biennial, guano is preferred for the second year. About 12 tons of farm manure per acre is the quantity used. The annual crop per acre averages 20 tons, the biennial 30 tons. The selling price is 36*s.* per ton.

Those engaged in cultivating the sugar-cane in Andalusia are well aware of the limited area upon which it can be grown, and have recently turned their attention towards the introduction of beetroot, as a substitute for the more delicate and susceptible plant. Some experiments have been made with a view to its acclimatisation; so that by causing the crops to come to maturity at different times of the year the working plant and factories would be utilised to a maximum. M. Grand is of opinion that by judicious management, in advancing one crop and retarding another, this object might be effected.

C. T.

On the Multiple System of Signalling.

(Annales Telegraphiques, Sept.-Oct. 1874, pp. 187-224.)

In every system of transmission, the line wire remains unoccupied during that fraction of time between the signals which is more than necessary for the discharge of the wire. The consequent loss of time becomes considerable where the rate of transmission depends upon the quickness of manipulation; because the time required for the mechanical operation of signalling is greater than that required by the current to pass and reproduce the signals: *e.g.*, the greatest number of dashes that an operator can send per second is five, while the wire can take and reproduce distinctly a much larger number.

To utilise these intervals is the aim of the Multiple System; which term implies the connection of more than one communicating post through the same line wire, each working simultaneously with, but independently of the other.

Take, for instance, two places communicating by the Morse system, and sending dots and dashes; between each of these signals the wires, being free, may be detached from the first pair of instruments, and when connected with a second pair, may send during the time of contact a dot or a dash.

If each pair of instruments has an interval sufficient for the longest signal (a dash), two distinct messages can be sent in the same time, these messages being not simultaneous, but successive.

Another method consists of spacing regularly, not the elementary signals, but the letters, by allowing for each letter an interval long enough for the longest (*ch*).

If an interval sufficient for the longest signal or letter is allowed for each, and between two successive signals an interval is left sufficient for $n-1$ dashes, or between two letters an interval for $n-1$ times the longest letter in the alphabet (*ch*), then during each part of an interval sufficient for a dash or *ch*, the terminals can be connected with a new pair of instruments, and the transmission of n distinct messages may be obtained in the time required for the single original message, while at the n communicating places, or posts, each sender and receiver will have at their disposal an amount of time which is at least n times longer than that required for the passage of the currents.

In principle, this system of multiple signalling is inferior to that of prepared messages, in which a complete separation is made between the personal work and the signalling proper, and where, in fact, each signal only takes up the time absolutely necessary for the passage of the currents. In the multiple system, the dot takes as long as the dash, and the shortest letter as long as the longest; the system of prepared messages therefore must be more economical of time, in the proportion of 2 to 1, that is of the longest letter (*ch*) to one of mean length (*u*).

To make the most out of the multiple system, this subdivision of time must be the shortest possible, and the number of signals passed during it the greatest. Suppose one clerk makes five dashes in a

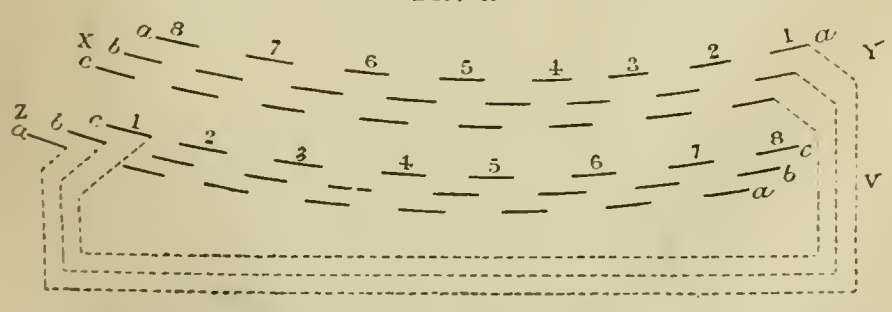
second, he will take $\frac{4}{5}$ of a second to make the longest letter, and will send seventy-five letters a minute; each subdivision, therefore, would be equal to $\frac{1}{75}$ of a minute. The number of distinct signals that can be transmitted in that time depends upon the electrical state of the line. Suppose the number of dashes the wire will transmit, clearly, per second to be equal to N: then $\frac{N}{5}$ is the number of clerks who can work at each end of the same wire.

Although the system of multiple signalling is disadvantagous, as compared with prepared messages, in so far as it requires an absolute synchronism between the corresponding stations, yet it possesses advantages in the facility given to each clerk for repeating, rectifying, and altering each individual message; while the manager is enabled more easily to proportion his staff to the varying requirements at different hours in the day; and there are greater facilities for corresponding from one central station to several outlying stations.

In the two machines known as the Rouvier and the Meyer, there must be at each end of the wire commutators moving in absolute synchronism, and the personal work, or signalling, must be subordinate to the motions of these commutators. In the Rouvier system the synchronism is obtained by pendulums, one at each end of the line, of equal length, oscillating between electro-magnets, which are actuated by make and break arrangements. The action is briefly as follows; each pendulum, towards the end of its stroke, makes a contact, by which the current in the line wire closes local circuits. These acting on an electro-magnet at each end, attract each pendulum during the fraction of its course which is reserved for correcting any departure from synchronism, until, by a second simultaneous contact of the pendulums, the line wire is insulated, the local circuits are opened, and the pendulums free to fall. But if this second contact of the two pendulums is not simultaneous, a current still passes in the line wire, the local circuit remains closed, and that pendulum which is in advance is retained till the other has come up to it.

Suppose it is required to work Rouvier's system of multiple signalling between two stations, and, for simplicity, let it be

FIG. 1.



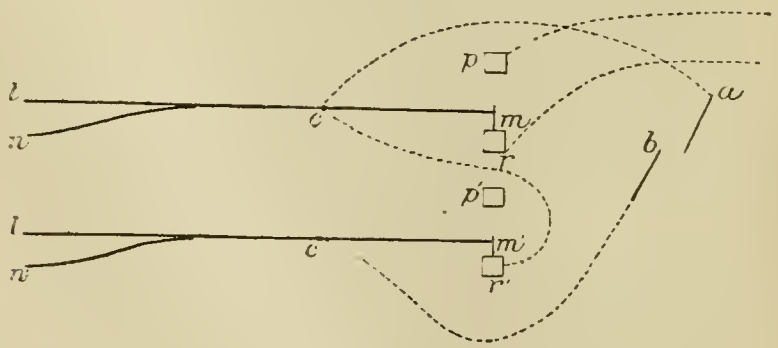
supposed that there are only two independent communicating posts. Take a plane, as shown in Fig. 1, parallel to the plane of

oscillation of the pendulum. Between the limits X Y eight triple contacts, insulated from each other, are disposed nearly as shown, and similarly between Z V. The surfaces of their contacts are concentric round the centre of oscillation of the pendulum, those between Z V are similarly situated radially to those between X Y, and their lengths are proportioned to the distance from the centre of oscillation. The groups between X Y are connected with the groups between Z V, so that *a* No. 1 of X Y on the right is joined to *a* No. 1 of Z V on the left, and similarly for the contacts *b* and *c*. All the contacts of the *c* rows have earth connection, and those of the *a* and *b* rows are connected with the signalling levers.

The pendulum has two sliding contacts, one for the row X Y and one for Z V, which come into work at alternate oscillations; from right to left the sliding contact for X Y comes into circuit, and from left to right that for Z V.

At each station all the contacts with odd numbers are in connection with the levers of a manipulator No. 1 for one post, and those with even numbers with the levers of a manipulator No. 1 for the other post. Thus at either station the pendulums have similar contacts at the same moment and for the same time, and in each oscillation each post of stations has its communication made and broken four times. Each manipulator is furnished with four pairs of levers, each pair being in connection with one of the contact groups of its series. Take group I. of series X Y or Z V, according as the oscillation is commencing from the left or the right. It has been shown that the similar contacts *a* of these groups are connected, the same being the case with the contacts *b*; *a* is joined to the lever *l* (Fig. 2, which is a diagram of any one pair of levers of a manipulator), and oscillates round *c* between the limits *p*, *r*; while

Fig. 2.



b is similarly joined to the lever *l'*, and oscillates between the limits *p'*, *r'*. The springs *n* and *n'* tend to keep the ends *m* and *m'* in contact with *r* and *r'*; *r* is in connection with the receiver of No. 1 post, *p* with the line battery, *r'* with the lever *l*, and *p'* is insulated, and similarly for the odd-numbered groups. In the same way even-numbered groups are connected to four pairs of levers forming the manipulators of No. 2 post, and communicating

with the receiver of this post. The connections at the other station are similar.

If, then, at the commencement of an oscillation, the lever *l* alone is pressed down, the current passes through both *a* and *b*, and thence to the receiving station, during the whole time the gliding contact of the pendulum is on them, and a dash is made. If both *l* and *l'* are pressed down, the current passes through *a* only, and a dot is made. As there are four such pairs, four dots or four dashes, or any combination of them, *i.e.*, any letter of the Morse alphabet, can be made by each post during each oscillation. Usually templates are employed, one for each letter, so cut as to press down the proper levers, and these are worked from a convenient key-board. The line is discharged at each alternation of instruments by the passage of the pendulums over the earth contacts *c*. In length these are made equal to a dot, which is the least space possible between two letters.

Another advantage of this system is that, time being given for demagnetisation, the inertia of the electro-magnets is only felt during the magnetisation. Following out this system, three key-boards can be worked on one line wire. It will likewise be seen that Steinheil's alphabet is applicable, on account of its shortness, because it is formed by a combination of signals of the same length (dots), from alternating currents, the negative being received on one strip of paper, and the positive parallel to it on another strip. In this case each lever of the sender must be a double one, and each receiver must have two polarised relays, one working to a positive and the other to a negative current. Meyer's system differs from Rouvier's in this respect, that the time of signalling each letter is that of the longest letter. The synchronism is obtained by a conical pendulum with an elastic spindle, which was fully described at p. 49 of the previous number of "Annales Telegraphiques."

An apparatus for quadruple signalling, that is with four posts on the same line, is described as follows:—Suppose at each end of the line a circular dial is divided into four equal parts, with a needle moving round it. If the needles move in synchronism, and start from corresponding points, they will always be at any moment on corresponding divisions; so if each quadrant at each station is in connection with a signalling post, the corresponding posts at the two stations will be successively and regularly in communication. The distributor K (Fig. 3) arranges the due distribution of the current both on the receivers at the signalling station and on those of the receiving station, so that the messages are reproduced at each. It consists of an ebony wheel divided into four quadrants, each of which is subdivided into twelve parts; each part consists of a sector of copper let into the ebonite, while a small interval separates the sectors. The first sector answers to a dot; the first and second together, to a dash; the third is an earth contact, which separates the individual signals of which each letter is composed. This group of three sectors is repeated four times in the same order in each quadrant. Thus

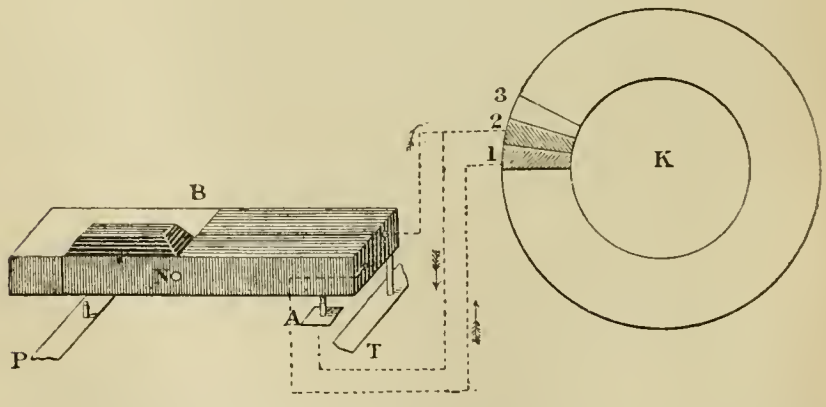
each quadrant contains the elements of each letter of the Morse alphabet.

The traversing needle, which is actuated by clockwork, communicates permanently through its axis with the line wire, and makes contact with each individual sector while passing over it. Thus if a sector is at the same time connected with the line battery a dot is sent, and if two consecutive ones are so connected a dash is sent; and each time the needle passes the third sector it is discharged into the earth, and prepared for the next signal.

There are four key-boards, one for each quadrant. Each key-board has four white keys for the dashes and four black ones for the dots. There is a key-board for each quadrant, and each key works a lever: that of the first black key is connected by an insulated wire with the first sector of the quadrant, that of the first white key with the second sector, and similarly for the second, third, and fourth black and white keys of each key-board, and the second, third, and fourth group of sectors in the corresponding quadrant.

Each lever serves to make contact with the battery P, and the earth T; but on depressing the first black key a current is sent from the battery into the first sector of each group, and makes a dot; while the white key sends it at once into the two first, and makes a dash. Depressing both keys produces the same effect as depressing the white key alone. Fig. 3 shows this arrangement: the black key,

Fig. 3.



when not being worked, does not communicate directly with the earth, but through contact A and the white key; and when the black key is depressed, the connection of it with the white key is broken. When it makes contact with A, the line current, passing through the first sector, goes to earth through A and the earth-plate of the white key. Each clerk has three-quarters of the duration of one revolution to prepare his letter on the key-board, and an oral signal duly informs him when his turn comes.

The electro-magnets of the receiving instrument (a printing one) are worked by a polarised relay, in such a way that the circuit from the local battery is always closed except when a line current passes; this opens the circuit, demagnetises the instruments, and by

ordinary mechanism presses the papers against the inking rollers. In the present instance, where there are four rollers, and four strips of paper to receive the message passing under them, arrangements have to be made that only one of these receives the message. This is done in the following way :—

Take a cylinder 0·2 mètre long, on which is cut in relief a screw thread having a pitch equal to the length of the cylinder; this is divided into four lengths of 0·05 mètre each. These are spaced equally at convenient distances along the same axis, but preserve their relative position; that is, on a plane perpendicular to the axis, the four quarter threads show as a complete circle. The transverse axis of these quarter screws becomes the axis of the needle which traverses the distributing dial, and the position of this needle in its passage over one of the quadrants corresponds to the position of one of these quarter screw threads with regard to one of the four strips of paper, so that on the passage of a line current it is this strip that receives the impression and no other.

The plane of the paper being a tangent to the surface of the screw thread, the fractions of the quarter revolution during which they are in contact are accurately represented by the lengths and positions of the lines on the paper, contact during the whole quarter revolution producing a line of 0·05 mètre across the strips of paper.

The contacts depending both as to length and frequency on the line currents, and these on the manipulation of the key-boards, it will be readily seen how, on pressing down, say the two first white keys and the two last black keys, during the passage of the distributing needle over any one quadrant at one end of the wire, two dashes followed by two dots will be presented by the corresponding roller at the other end. A sound-signal also duly gives notice to each clerk when his particular receiving instrument is on.

When the synchronism is perfect, the successive rows of printed letters form a column parallel to the sides of the strip of paper, each letter being about 3 millimètres distant from its forerunner. To keep this synchronism perfect—for slight errors would quickly accumulate if the conical revolving pendulums were left to themselves—a special arrangement, as in Rouvier's system, has to be made. For this purpose a small fraction of the circumference of each distributor, about one-twelfth, is reserved for correction; the other division of the distributing dial and the screw threads of the receiver being modified to allow of this.

The correcting machinery is at one end only of the line; from the other end, during the 'correcting interval,' a current goes, is received in the polarised relay, and runs to earth through an independent electro-magnet, E. To insure that this earth connection should not be open except during this interval is one of the duties of the clockwork of the correcting machinery. As the rate at which the regulating pendulum revolves depends upon the tension of its elastic spindle, a clockwork movement can be made slightly to tighten this during one-half the interval, and lengthen it again

during the other half. Suppose this tightening and slackening to be transmitted from the clockwork to the pendulum spindle through a connection formed by the magnetisation of the electro-magnet E; then, if the time of tightening is equal to the time of slackening, which is the case when the movements of the distributing needles at each end are synchronous, no change takes place in the mean rate of revolution. But if the tightening machinery is coupled to the pendulum spindle for a shorter period than the slackening machinery, the pendulum will make its revolution a fraction slower.

It will be seen that in this system of printing the messages, the different combinations to form a letter need not be dependent simply on their size and number, as in the ordinary Morse alphabet, but also on their relative position and distance from each other. Hence, an immense number of additional signals can be made. The duty done by a multiple signalling apparatus is easily obtained from the number of turns per minute made by the distributor, and the number of posts in communication through the same wire; for instance, an apparatus for four pairs of posts making 75 turns per minute will make 300 letters per minute, leaving an interval equal to a letter between each word. A word may be taken as consisting of 6 letters, equal to 50 words per minute and 3,000 per hour; and if a message be taken as consisting of 30 words, 100 single messages per hour may be counted on.

This result has been verified by practice between Paris and Lyons. Each clerk sends 22 to 25 messages per hour, giving 88 to 100 as the number sent by the single wire. The number has been raised to 110 per hour per wire by increasing the revolutions of the distributor to 85. This is more than twice the result obtained by the Hughes apparatus, the number of clerks being equal.

An apparatus for six double posts is now being made between Paris and Lyons, and one between Paris and Marseilles, to work at 65 revolutions per minute.

F. W.

Freezing by Capillary Attraction combined with Evaporation.

By M. C. Decharme, Professor of Physics at the Lycée of Angers.

(Annales de Chimie et de Physique, Oct. 1874, pp. 236–267, 2 pl.)

The Author, after describing at some length his experiments with highly volatile fluids, gives the following résumé. When one extremity of a porous body, such as blotting-paper, is immersed in a highly volatile liquid, such as bisulphide of carbon, capillary action at first causes the liquid to rise about an inch on the paper; evaporation then arrests the upward motion, by producing so great a fall of temperature that atmospheric vapour congeals upon the paper in various arborescent forms, until the fluid has

become exhausted. One of the results of this observation is, to provide a simple process for ascertaining at all times, in the open sunshine, in a room, or in a closed vessel, the presence of vapour in the surrounding atmosphere, and its relative or absolute quantity. On the 13th of July, 1874, in the open sunshine, the temperature being 105° Fahr. (40°·6 C.), with a slight north-west wind and the barometer at 29·98 inches (760·5 millimètres), arborescents were formed upon the porous papers, similar to those observed on damp days in autumn or in spring.

When a scroll of blotting-paper is dipped into the bisulphide of carbon and immediately withdrawn, the zone of rime forms in twenty or thirty seconds (sometimes less), increases for one minute, and melts. This method of ascertaining instantaneously, even in the sun, the presence of vapour in the atmosphere, presents during a fog still more decided phenomena. It is a hygroscope not only of great simplicity, but capable of being rendered very accurate.

The experiments have also furnished a new means of artificially freezing water. In order to operate rapidly, it is sufficient to envelop with blotting-paper a small glass tube, about the size of a quill, containing an inch in height of water, to plunge it into the bisulphide of carbon, and withdraw it immediately: freezing takes place in two minutes at an air temperature of 59° Fahr. (15° C.). When put under a suitable microscope the operation of congelation can actually be followed with the eye—Nature, as it were, can be seen at work, and it is plain that the arborescents are not produced by a hydrate of the substance, but simply by a congelation of the vapour in the atmosphere. Substances dissolved in the bisulphide of carbon, such as sulphur, iodide, bromide, &c., do not obstruct the process of congelation, but modify its effects in their own specific manner. Amongst the substances of which the boiling point is low, the following have given frozen arborescents, white or coloured, according to the nature of the liquid: bisulphide of carbon, chloroform, sulphuric ether, hydrochloric ether, hydrobromic ether, hydriodic ether, and super-hydrochloric ether (chlorhydrique chloré).

J. D. L.

Mechanical Production of Cold by the Expansion of Air.

By Jules Armengaud, jun.

(Annales Industrielles, June, July, and August, 1874, 34 cols.)

The whole theory is deduced from the formulæ (1) and (2) of Thermodynamics.

$$\left.\begin{aligned} &\frac{p\,v}{a+t} = \mathrm{R}, \text{ or } p\,v = \mathrm{R}\,(a+t), \text{ in French units} = \mathrm{R}\,\tau \\ &\frac{p\,v}{a+t-32^\circ} = \mathrm{R}, \text{ or } p\,v = \mathrm{R}\,(a+t-32^\circ), \text{ in English units} = \mathrm{R}\tau \end{aligned}\right\} (1)$$

In which $\frac{1}{\alpha}$ is the coefficient of expansion for air, $R = \frac{p_0 v_0}{\alpha}$ $= 29{\cdot}27$ in French units, or $53{\cdot}1$ in English units, v_0 being the volume of a unit of air, in weight, at the temperature of melting ice, p_0 the pressure of one atmosphere, τ the absolute initial temperature.

$$\frac{p}{p'} = \left(\frac{v'}{v}\right)^{\frac{c_p}{c_v}} \quad . \quad . \quad (2)$$

in which c_p is the specific heat of air with a constant pressure, and c_v the specific heat of air with a constant volume.

The fall of temperature resulting from the mechanical expansion of a gas is expressed by,

$$t - t_1 = \tau\left(1 - \frac{v^n}{v^n{}_1}\right) = \tau\left(1 - \frac{1}{z^n}\right)$$

$\frac{v_1}{v}$ being denoted by z, and n being $\frac{c_p}{c_v} - 1 = 0{\cdot}41$.

If $t = +\ 20°$ centigrade $= +\ 68°$ Fahrenheit, and $z = 2$, $t - t_1$ $= 72°$ centigrade, or $161°{\cdot}6$ Fahrenheit.

As a unit of weight of air in passing from t to t_1, under a constant pressure, p, will absorb a quantity of heat $c_p\,(t - t_1)$.

A unit of weight of air which has done work in proportion to an expansion z produces C negative thermal units

$$C = c_p \tau\left(1 - \frac{1}{z^n}\right).$$

When $z = 2$ C $= 17{\cdot}2$ French cold units, or C $= 31$ English units of cold.

The motive power required for the mechanical production of cold is the difference between that absorbed by the compression of the air and that restored during its re-expansion. The amount of work absorbed by the compression will be different, according as the cooling of the air takes place after its compression, or while compression is going on. When the air is cooled after compression in a condenser the work f_a expended by the compression of a unit of weight of air is shown to be

$$f_a = \frac{c_v}{A} \tau\,(z^n - 1).$$

The total work in the compression cylinder is also shown to be

$$F_c = \frac{c_v}{A} \tau\,(z^n - 1) + p\,v_3 - p_1 v_2 = \frac{c_p}{A} \tau\,(z^n - 1)$$

in which A is the inverse of J, the mechanical equivalent of heat; $p\,v_3$ is the work absorbed in compressing the unit of air in the condenser, v_3 being the volume of the air after being compressed to a pressure p; and $p_1 v_2$ is the work resulting from the counter-

pressure of the atmosphere on the free face of the piston, v_2 being the volume of a unit of air at the pressure p_1 of the atmosphere.

When $z = 2$ $F_c = 9{,}677$ kilogrammètres. $F_c = 31{,}860$ foot pounds.

When the air is cooled during compression so that the temperature remains constant, the work f_b required for compression is given by the formula which is used for the steam-engine:

$$f_b = p\,v\,\mathrm{L}\frac{v_2}{v} = p\,v\,\mathrm{L}\,z^{n+1} = \mathrm{R}\,\tau\,\mathrm{L}\,z^{n+1}$$

in which L denotes the Naperian or hyperbolic logarithm.

To obtain the effective work F_c the work of compression $p\,v$ and of counter-pressure $p_1\,v_2$ must be added and subtracted. But as the temperature is constant these are equal to each other; and therefore $F^c = f^b$, whence

$$F_c = \mathrm{R}\,\tau\,\mathrm{L}\,z^{n+1}.$$

When $z = 2$, $F_c = 8{,}385$ kilogrammètres. $F_c = 27{,}527$ foot pounds.

The work restored during expansion is shown to be

$$f_d = \frac{c_v}{\mathrm{A}}(t - t_1), = \frac{c_v}{\mathrm{A}}\,\tau\left(1 - \frac{1}{z^n}\right)$$

and since it is equal to the internal heat which has disappeared, $p\,v$ must be added to f_d, and $p_1\,v_1$ must be subtracted from it to obtain the total work F_d; whence

$$F_d = \frac{c_p}{\mathrm{A}}\,\tau\left(1 - \frac{1}{z^n}\right).$$

When $z = 2$, $F_d = 7{,}288$ kilogrammètres. $F_d = 23{,}941$ foot pounds.

The total motive force T_a, when cooling takes place after compression, is shown to be

$$T_a = F_c - F_d = \frac{c_p}{\mathrm{A}}\,\tau\left\{z^n + \frac{1}{n} - 2\right\}.$$

When $z = 2$, $T_a = 2{,}385$ kilogrammètres. $T_a = 7{,}901$ foot pounds.

The comparison of T_a with the number of cold units produced, shows that

$$\frac{T_a}{C} \text{ or } J_f = \frac{z^n - 1}{\mathrm{A}} = \mathrm{J}\,(z^n - 1).$$

J_f being the number of kilogrammètres or foot pounds that must be expended to obtain a negative thermal unit.

When $z = 2$, $J_f = 139$ kilogrammètres $= 253{\cdot}2$ foot pounds.

The total motive force T_b, when cooling takes place during compression, is shown to be

$$T_b = F_c - F_d = \frac{c_p}{\mathrm{A}}\,\tau\left\{n\,\mathrm{L}\,z - \left(1 - \frac{1}{z^n}\right)\right\}.$$

When $z = 2$, $T_b = 1{,}097$ kilogrammètres. $T_b = 3{,}590$ foot pounds.

In this case

$$\frac{T_b}{C} \text{ or } J_f = J \frac{n \operatorname{L} z + \frac{1}{z^n} - 1}{1 - \frac{1}{z^n}}.$$

When $z = 2$, $Jf = 64$ kilogrammètres. $J_f = 116$ foot pounds.

The variation of J_f with the expansion is fully discussed in the original Paper. It is also shown that, when the cooling of the air takes place during its compression, the work expended is 50 per cent. less than when cooling takes place after its compression.

S. D.

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Fig 1

Fig 3

Fig 4

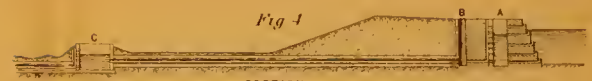


Fig 5

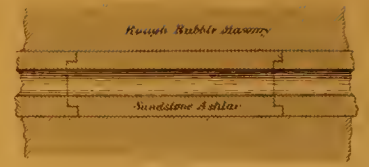


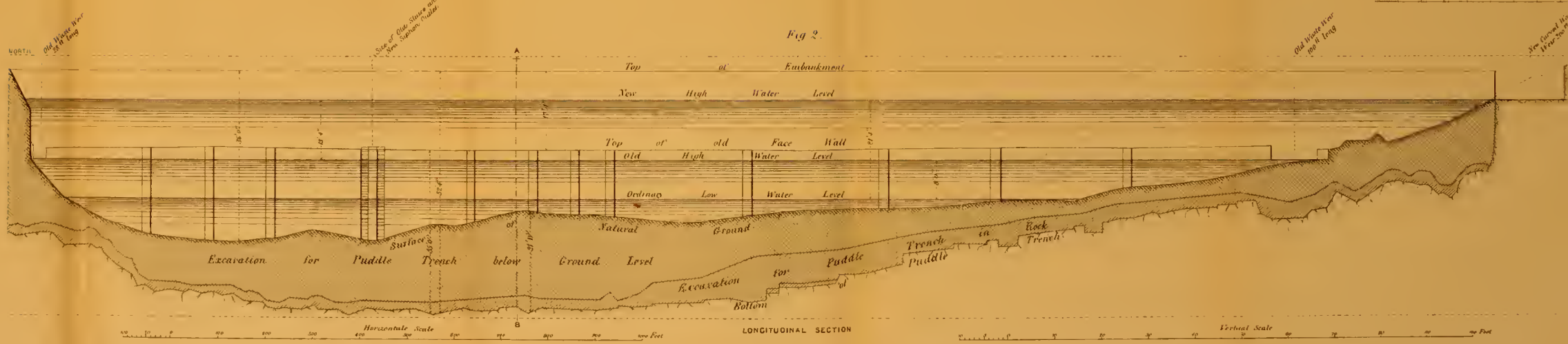
Fig 7.

MASONRY PIPE

REGULATING CHAMBER IN CITY

Scale for Details

Fig 2.



ALEX R RINNIE DEL.

Fig 3

PLAN

Fig 4

SECTION

Fig 5

Rough Rubble Masonry

Sandstone Ashlar

SECTION

Fig 6

CROSS SECTION

MASONRY PIPE

Fig 7

PLAN

Fig 8.

SECTION

REGULATING CHAMBER IN CITY

Fig 10

CONTOUR PLAN

Old Waste Weir 100 ft long

New Carriage Waste Weir 200 ft long

SOUTH

Trench in Rock

Trench in Puddle

Vertical Scale

Fig 9

New Top Water Mark

Old Top Water Mark

Surface Black Soil

Old Cotton Filling

Embankment

Earth from Puddle Trench Excavation

Original Surface of Ground

Puddle Wall

Old Puddle Wall

Surface of Rock

CROSS SECTION AT A B

Scale

Trans. Inst. C.E. Vol. XXXIX. Sess. 1874-75. Part I.

THOS. REES, LITH. 40 KING ST. COVENT GARDEN

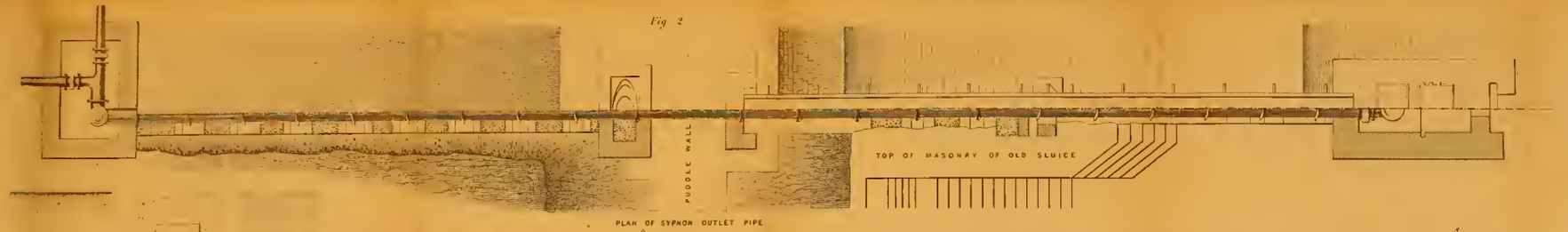


Fig 2
PUDDLE WALL
TOP OF MASONRY OF OLD SLUICE
PLAN OF SYPHON OUTLET PIPE

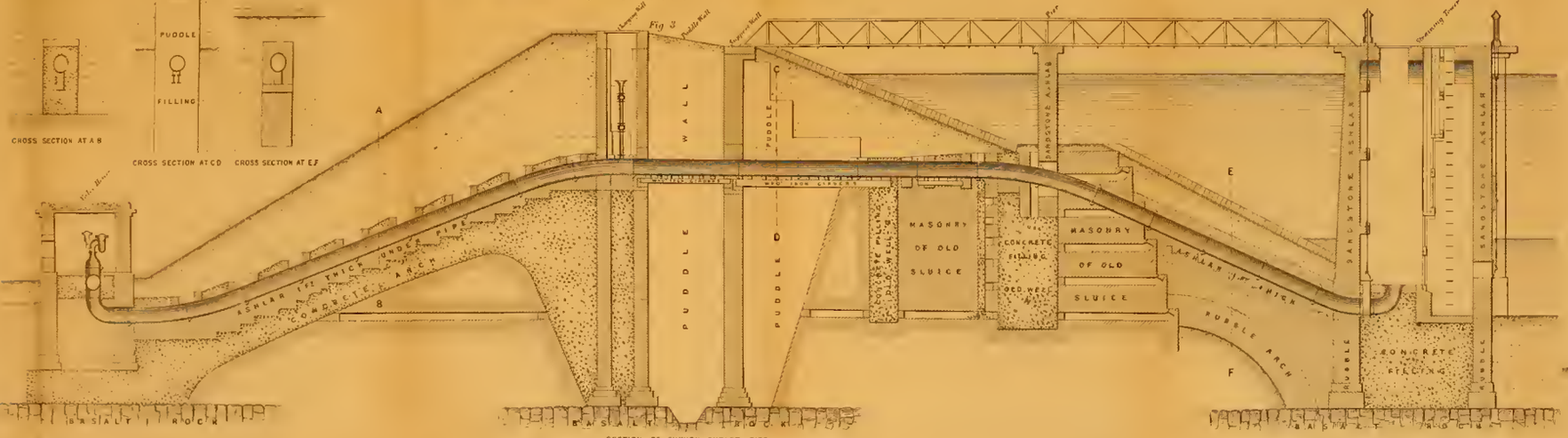


Fig 3
PUDDLE
FILLING
CROSS SECTION AT A B
CROSS SECTION AT C D
CROSS SECTION AT E F
PUDDLE WALL
MASONRY OF OLD SLUICE
CONCRETE FILLING
SANDSTONE ASHLAR
ASHLAR LIT THICK UNDER PIPE
CONCRETE ARCH
PUDDLE ARCH
BASALT ROCK
SECTION OF SYPHON OUTLET PIPE.
Scale 8 Feet = 1 Inch

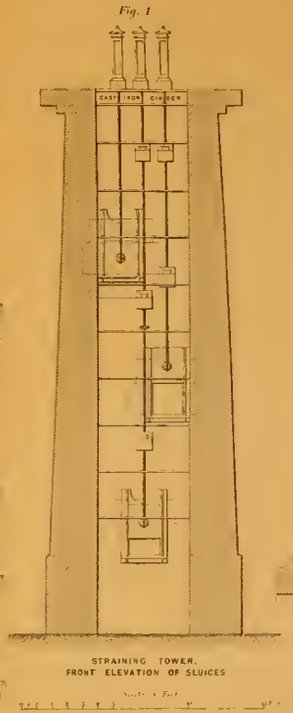


Fig. 1
STRAINING TOWER.
FRONT ELEVATION OF SLUICES

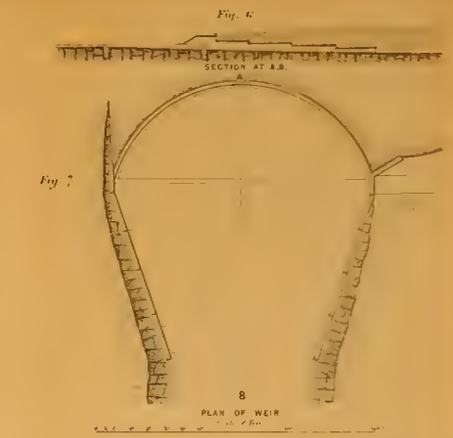
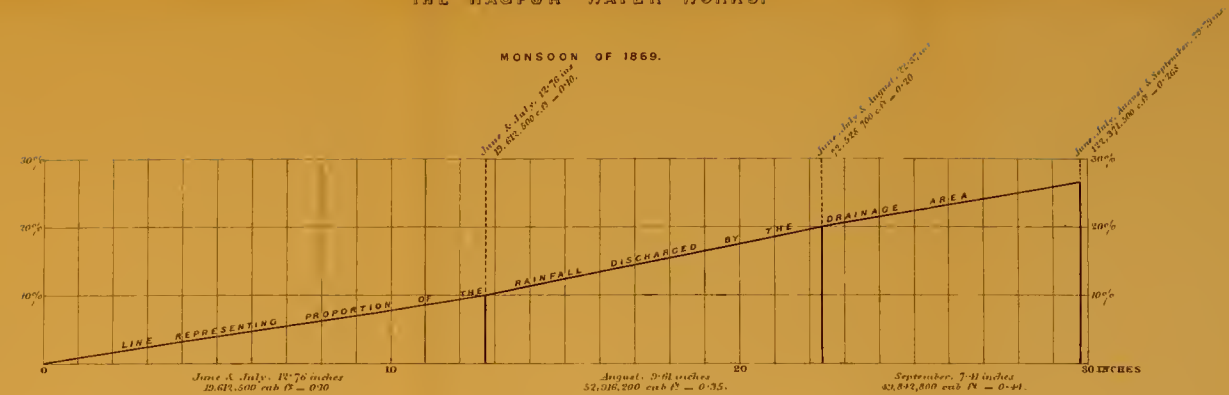


Fig. 6
SECTION AT A.B.
Fig 7
PLAN OF WEIR
Fig. 4
SYPHON PIPE JOINT.
Fig. 5
TRANSVERSE SECTION OF PIPE.

MONSOON OF 1869.

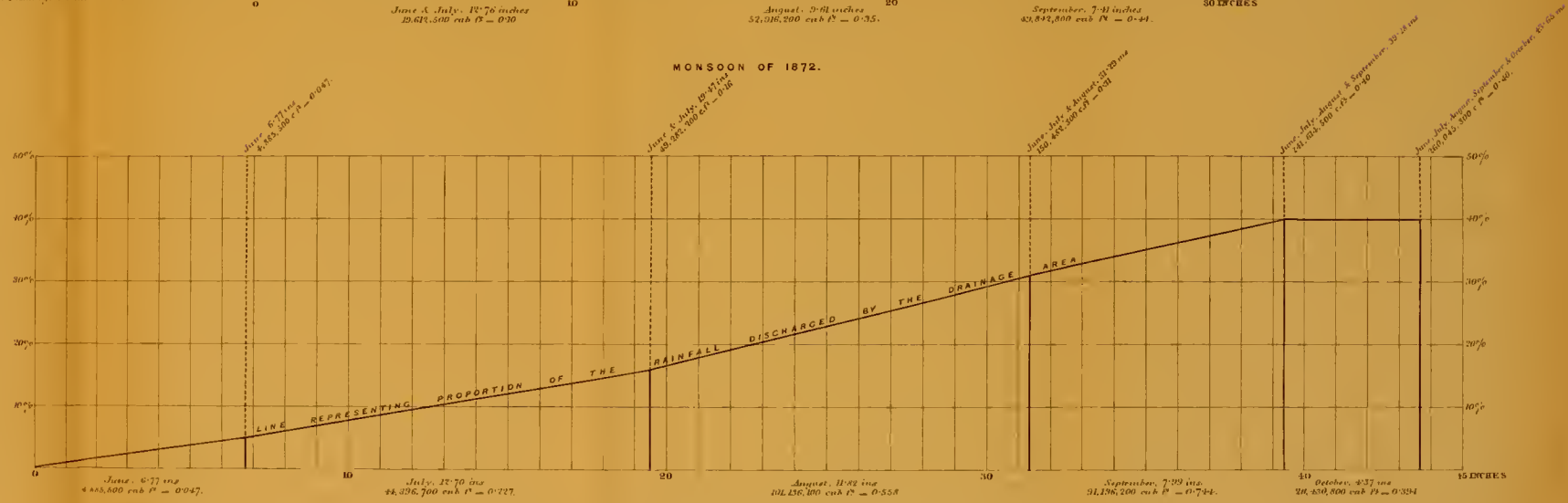


NOTE.

The Horizontal Figures below the Diagrams refer to the Rainfall and Discharge of each month separately.

The Figures at the Top of the Diagrams refer to the Rainfall and Discharge for the Totals of the months noted

MONSOON OF 1872.



DIAGRAMS OF THE DISCHARGE OF RAINFALL FROM THE DRAINAGE AREA OF 4224 ACRES.

Horizontal Scale : 1 Inch of Rain = ¼ Inch
Vertical Scale : each 10 per cent discharged = ½ Inch

ALEX^R & PINNIE, DEL.

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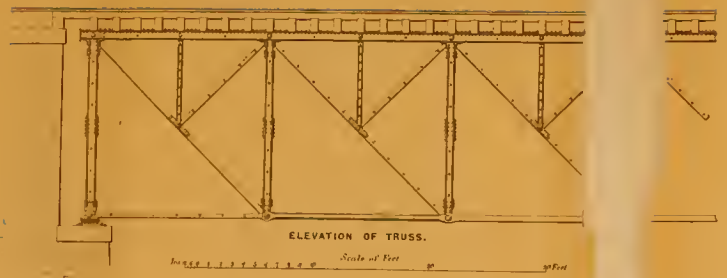
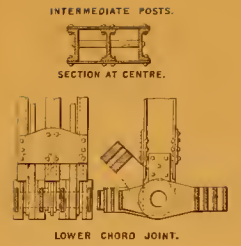
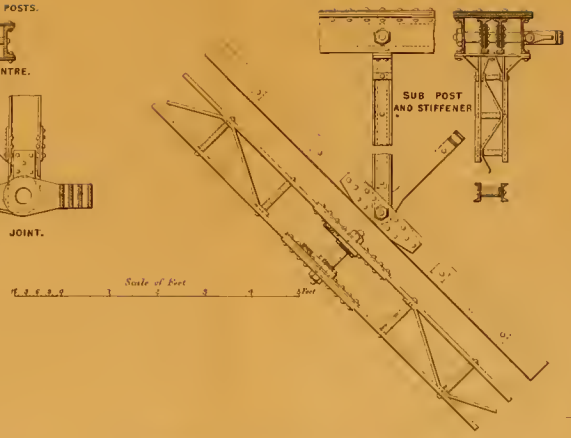
WM. KELL, 14TH 40, KING'S [illegible] GARDEN

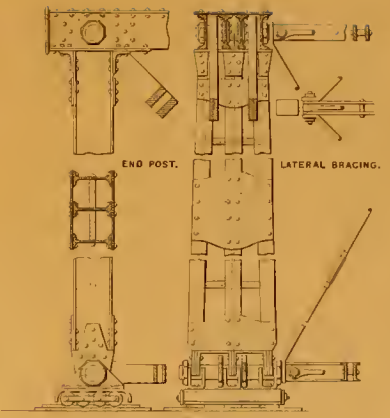


PE STIFFENED TRIANGULAR TRUSS.

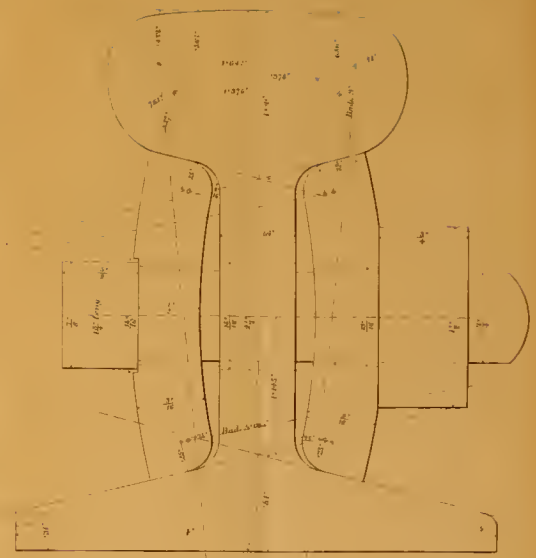




GENERAL ELEVATION OF BRIDGE.



WROUGHT IRON BOLSTER AND PLATE.
Wilson's Patent, March, 1874.



SECTION OF STANDARD RAIL AND FISHPLATES.

THE PENNSYLVANIA RAILROAD.

DIAGRAMS OF STANDARD ENGINES

Fig 1.

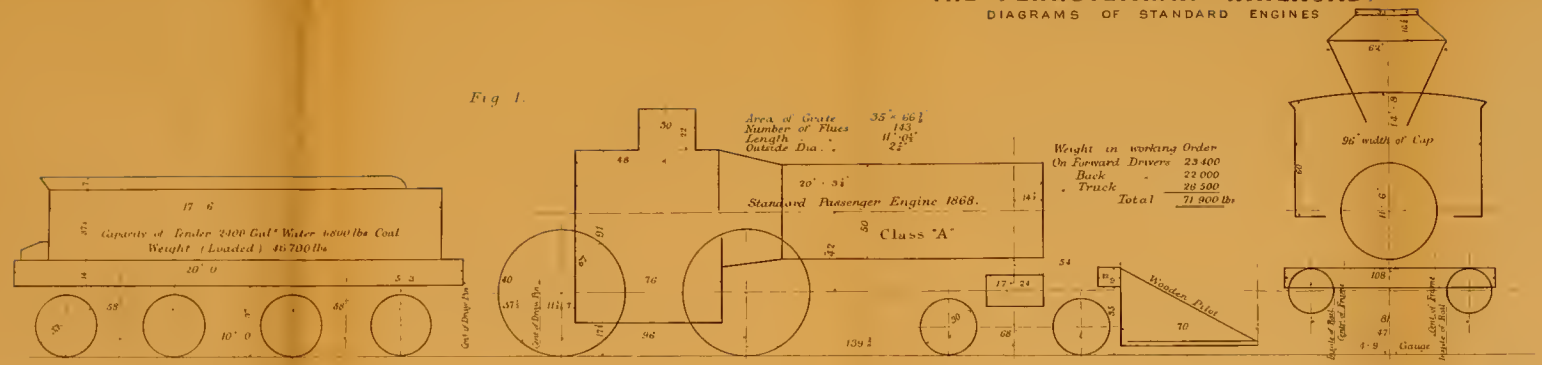

Area of Grate 35 × 66½
Number of Flues 143
Length 11' 0½"
Outside Dia. 2¼"
Weight in working Order
On Forward Drivers 23 400
" Back " 22 000
" Truck " 28 500
Total 71 900 lbs
Standard Passenger Engine 1868.
Class "A"
Capacity of Tender 2400 Gal.s Water 4800 lbs Coal
Weight (Loaded) 45700 lbs
96" width of Cap
Wooden Pilot
Spread of Cylinders and distance between Pistons, same on all Stand.d Engines. Widest tube (B.D.E.& G Engs) 6' 2"

Fig 2.

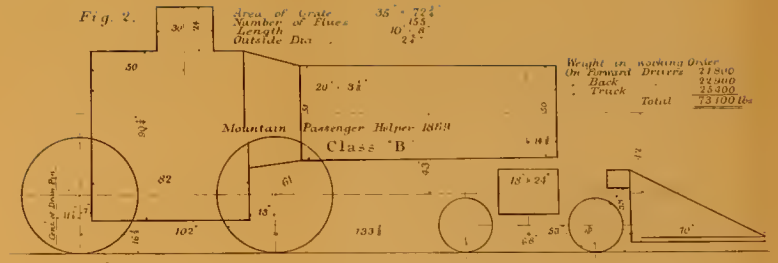

Area of Grate 35 × 72½
Number of Flues 153
Length 10' 8"
Outside Dia. 2¼"
Weight in working Order
On Forward Drivers 21 800
" Back " 22 900
" Truck " 23 400
Total 73 100 lbs
Mountain Passenger Helper 1868
Class "B"

Fig 3

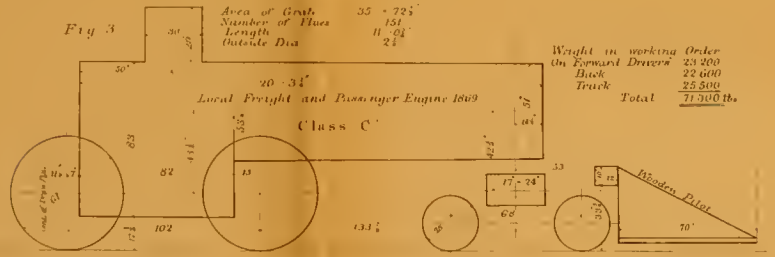

Area of Grate 35 × 72½
Number of Flues 151
Length 11' 0½"
Outside Dia 2¼"
Weight in working Order
On Forward Drivers 23 300
" Back " 22 600
" Truck " 25 500
Total 71 500 lbs
Local Freight and Passenger Engine 1869
Class "C"
Wooden Pilot

Fig 4

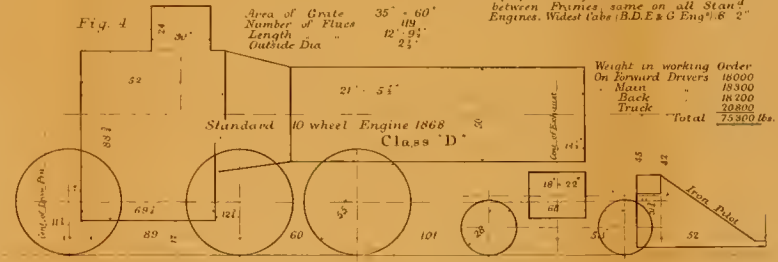


Fig 5

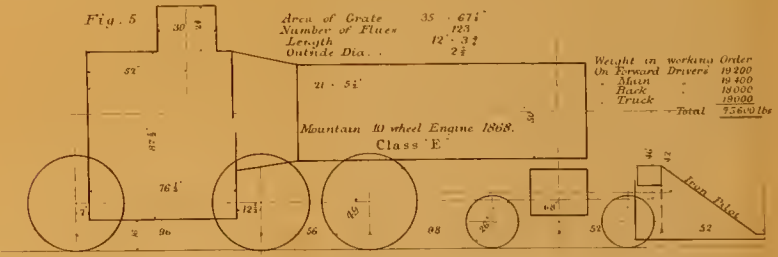
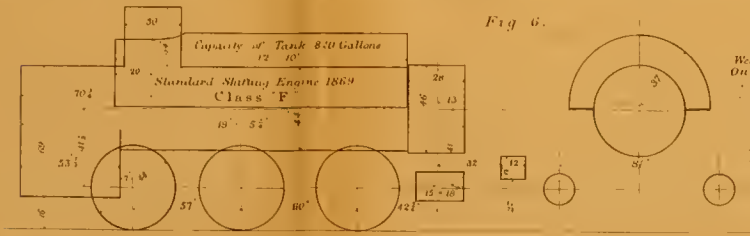


Fig 6.


Capacity of Tank 850 Gallons
Standard Shifting Engine 1869
Class "F"
Weight in working Order
On Forward Drivers 19 350
" Main " 22 450
" Back " 21 300
Total 63 500 lbs
Area of Grate 35 × 44½
Number of Flues 89
Length 12' 6"
Outside Dia 2¼"

Note: The Tenders for Figs 2 3 4 & 5 are the same as for Fig 1.

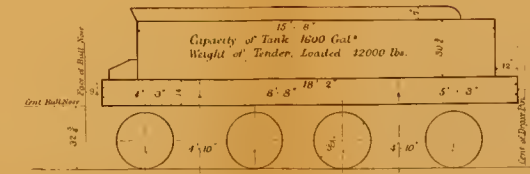
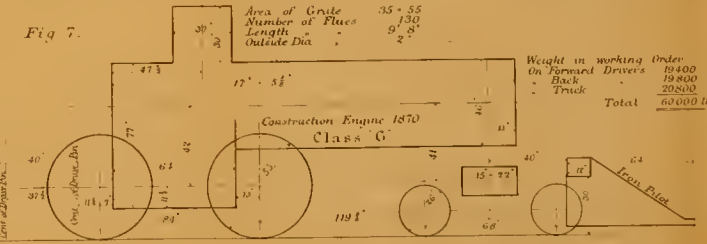
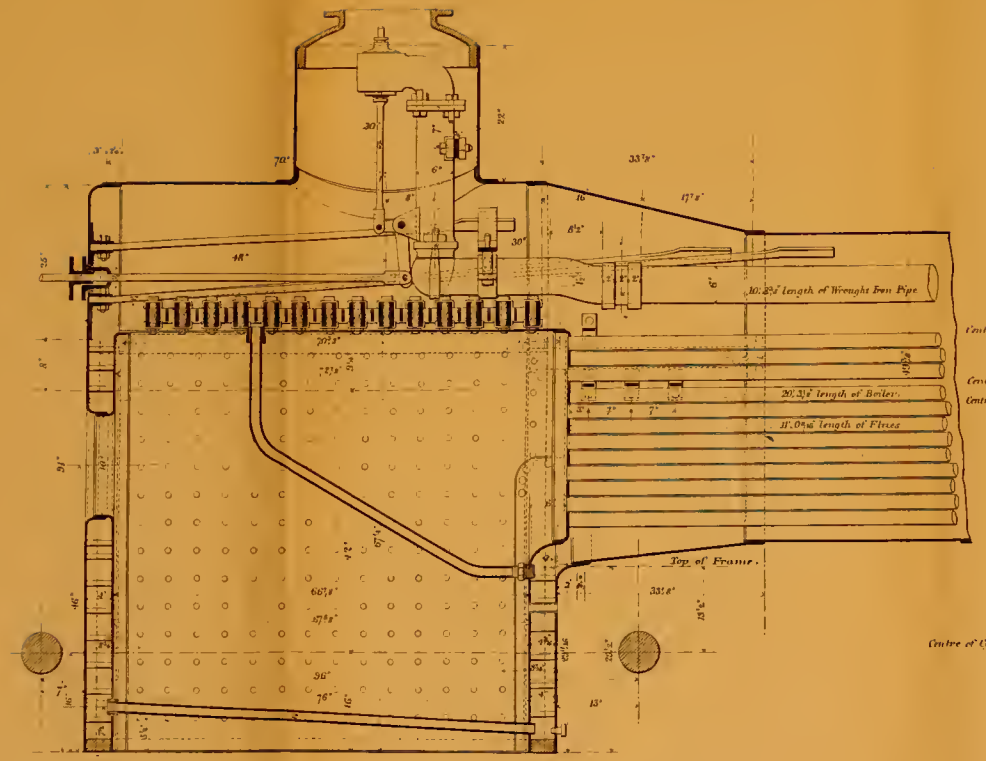


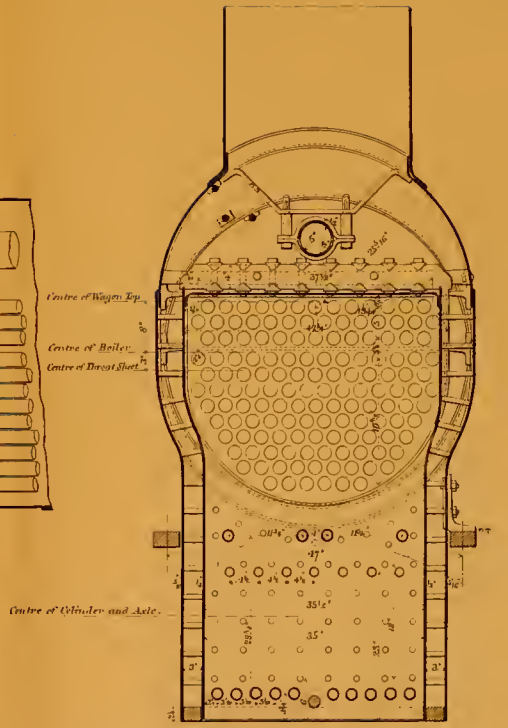
Fig 7.



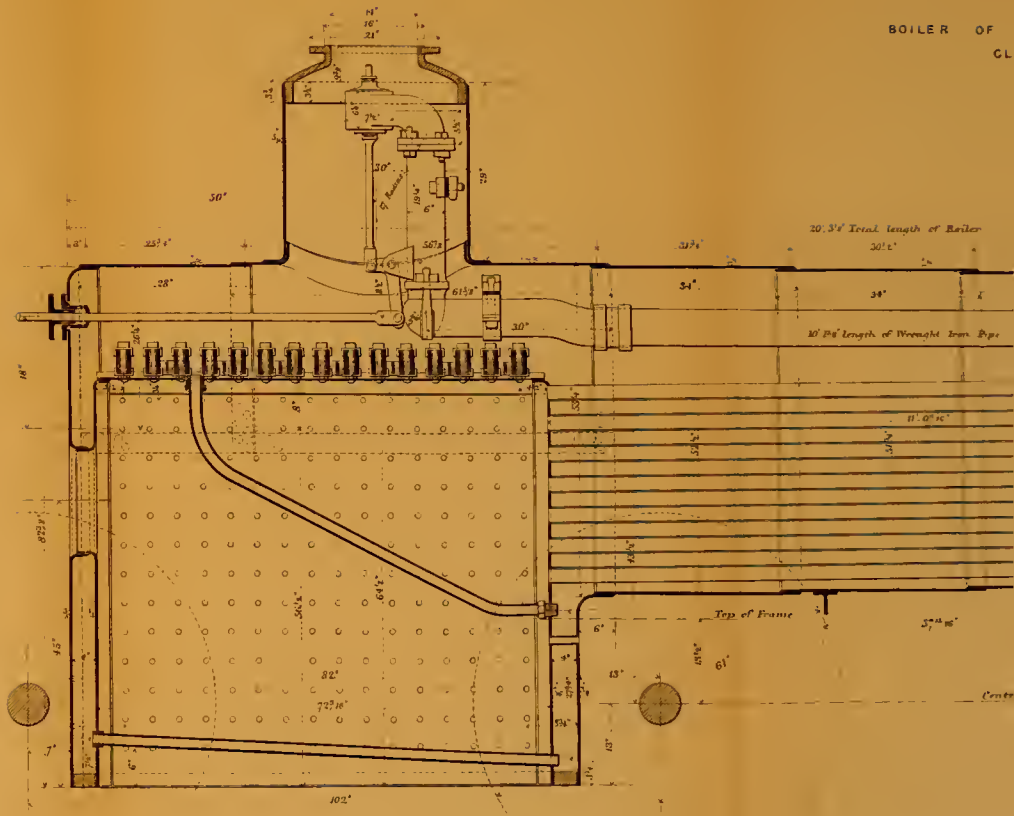
BOILER OF STANDARD ENGINE.
CLASS "A"



PART LONGITUDINAL SECTION.



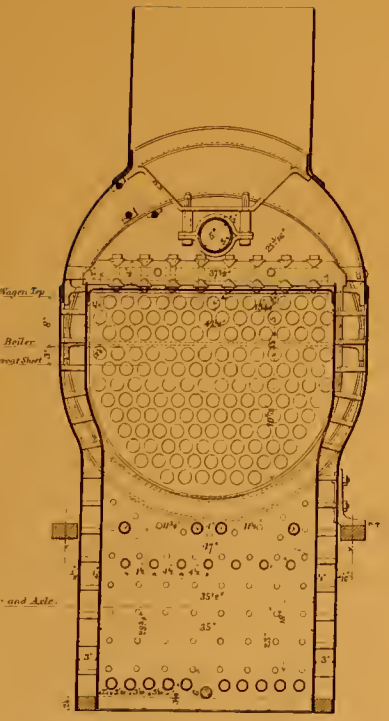
GROSS SECTION THROUGH FIREBOX.



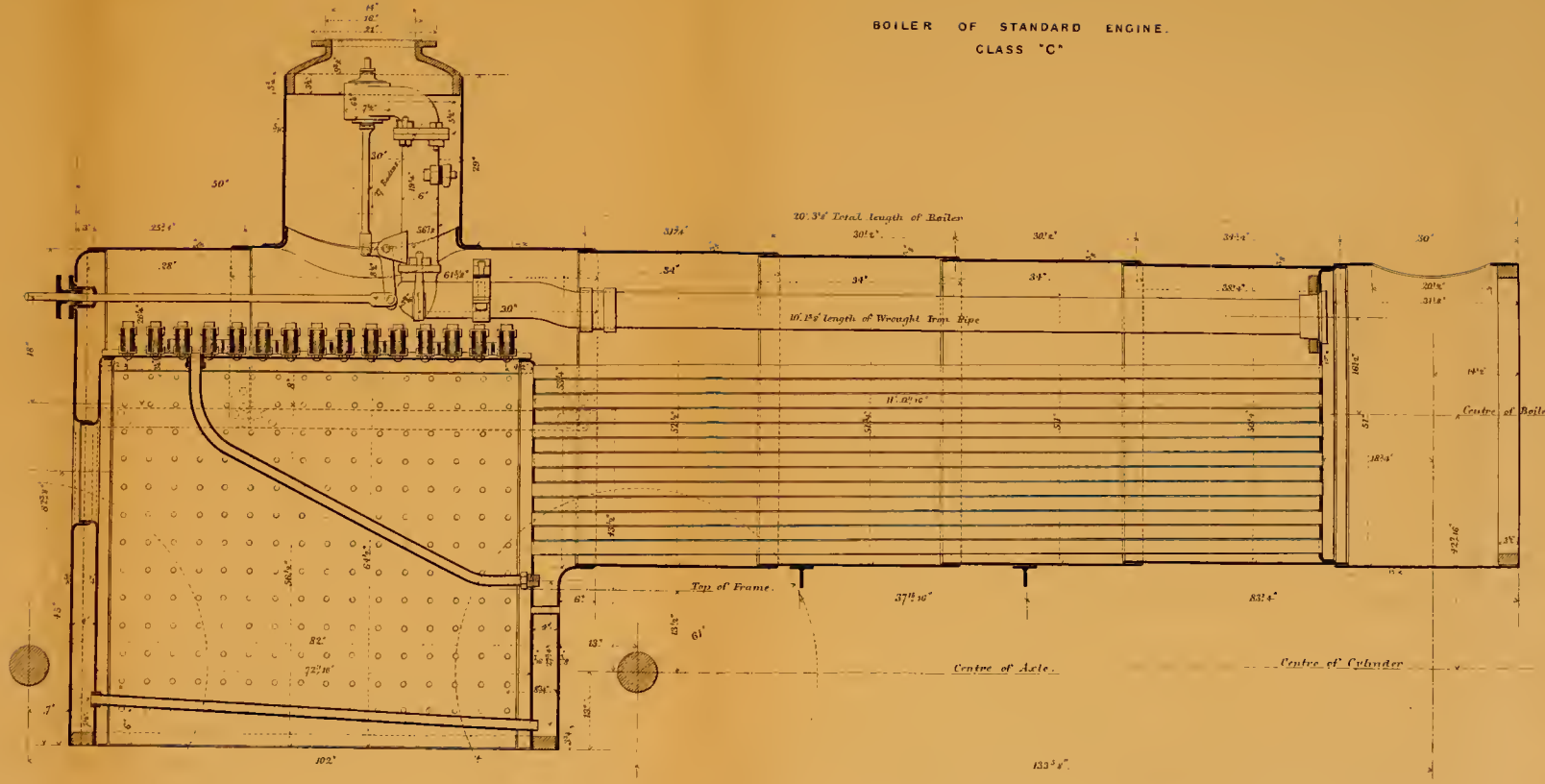
BOILER OF
CL

LONGITUDINAL SEC

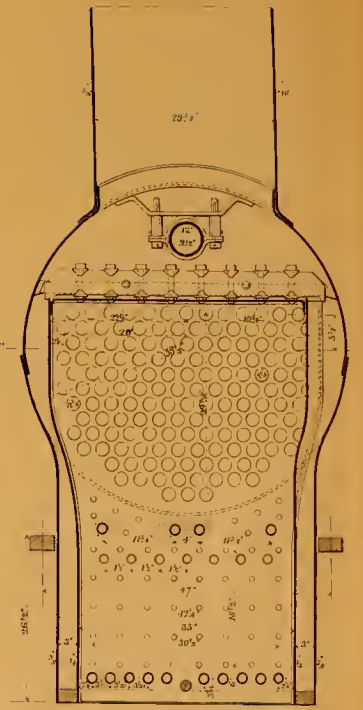
BOILER OF STANDARD ENGINE.
CLASS "C"



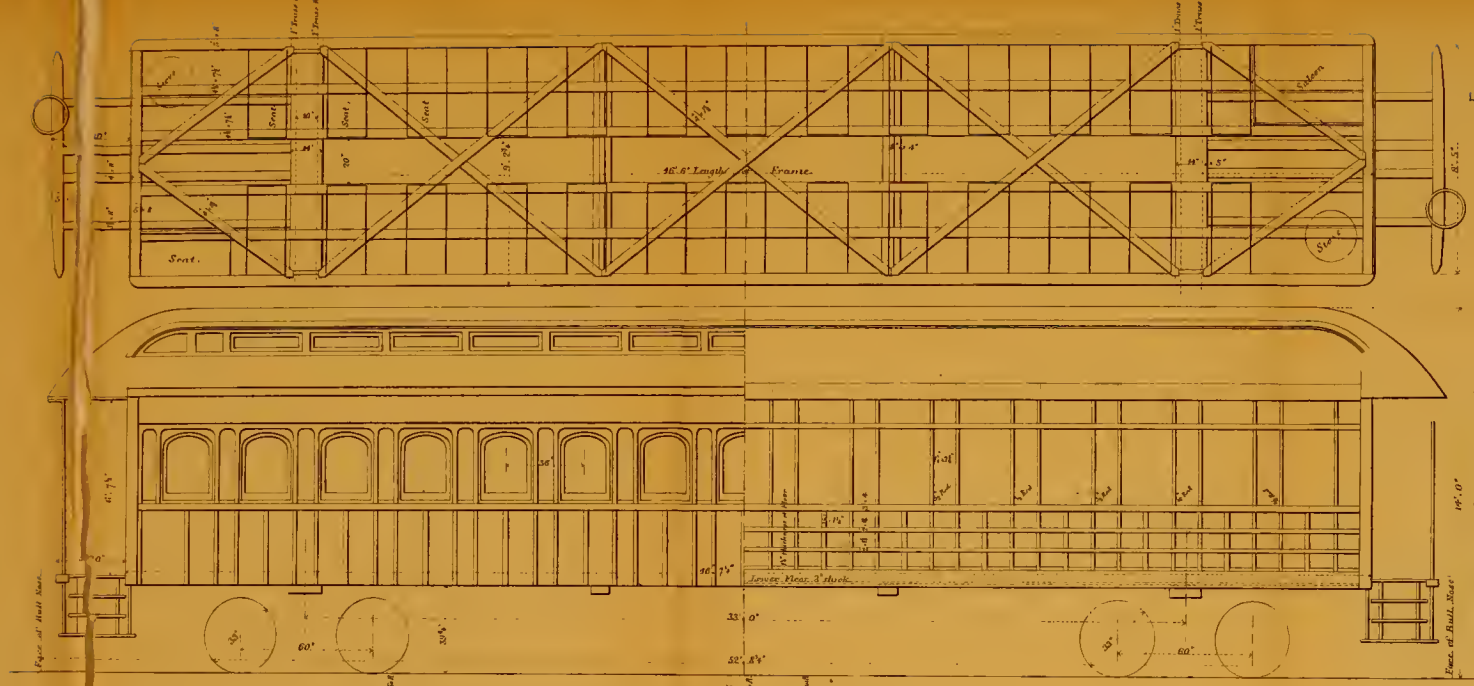
CROSS SECTION THROUGH FIREBOX.



LONGITUDINAL SECTION.

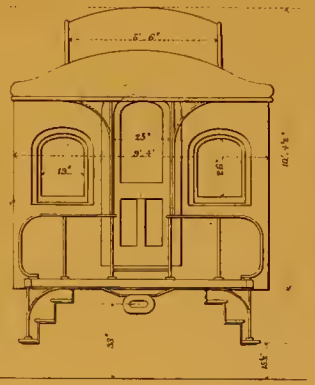


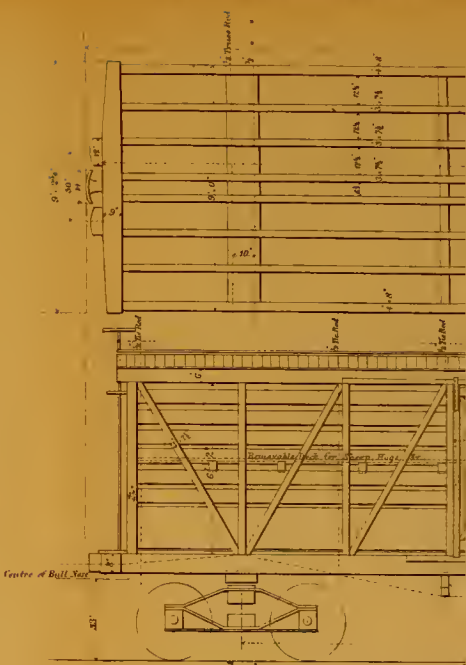
CROSS SECTION THROUGH FIREBOX.

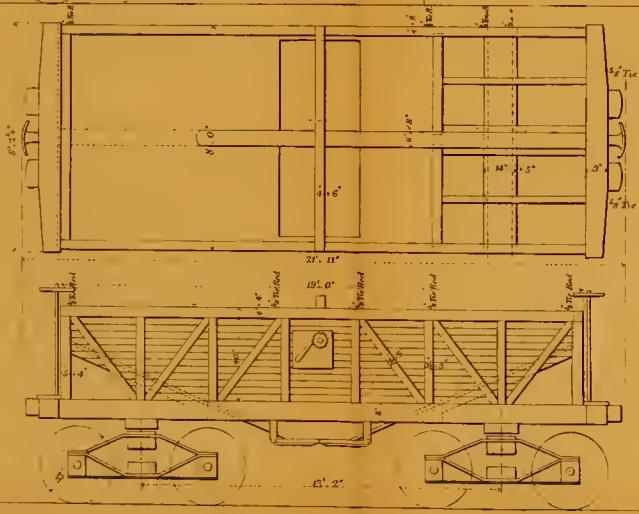


LIGHT PASSENGER CAR FOR LOCAL TRAINS.
Weight 31,000 lbs. Carries 54 Persons.

The Standard Passenger Car resembles this in general appearance, but is made of somewhat heavier timbers, carries 52 Persons and weighs 38,000 pounds.






Tie Rod.
Tie Rod
23'. 11"
19'. 0"
Tie Rod
Tie Rod
Tie Rod

STANDARD STOCK CAR.

STANDARD BOX CAR.

STANDARD DROP-BOTTOM GONDOLA CAR.

For Carrying Coal and Lumber.

The "Ordinary Gondola" differs from this only in having two Centre Stringers like Box Car and no Drop Doors.

SNOW PLOUGH.

Scale ¾ Inch = 1 Foot

LONGITUDINAL SECTION.

HALF END ELEVATION.

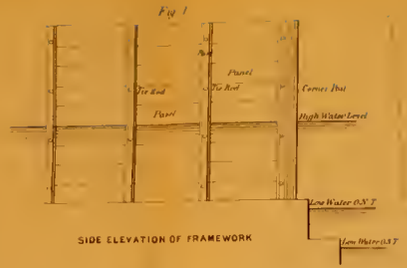
HALF CROSS SECTION

SECTIONAL PLAN.

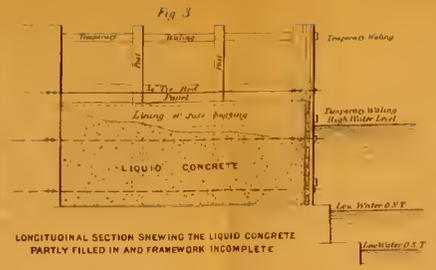
TH. S BELL LITH 40 KING ST COVENT GARDEN

ABERDEEN HARBOUR.

NEW SOUTH BREAKWATER

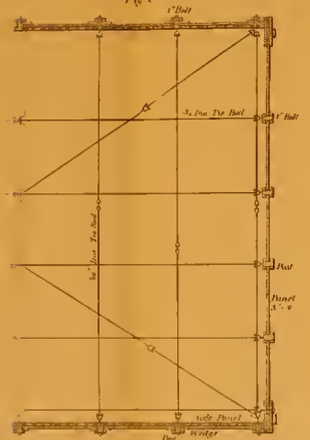


SIDE ELEVATION OF FRAMEWORK

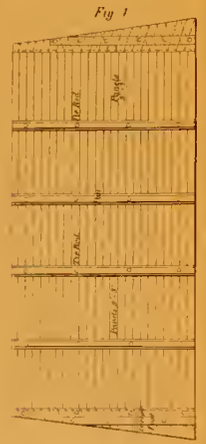


LONGITUDINAL SECTION SHEWING THE LIQUID CONCRETE PARTLY FILLED IN AND FRAMEWORK INCOMPLETE

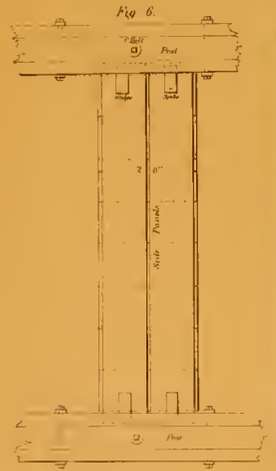
SECTION OF SIDE OF FRAMEWORK



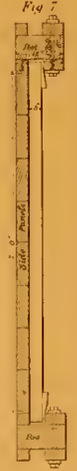
SECTIONAL PLAN



ELEVATION OF END



ELEVATION

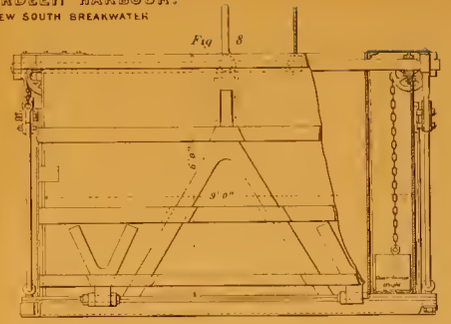


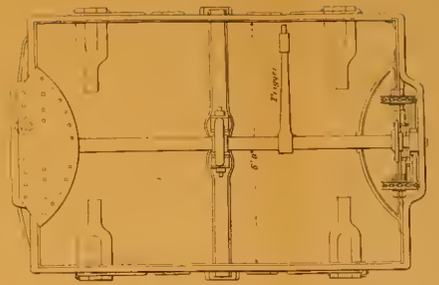
CROSS SECTION

FRAMEWORK USED FOR LIQUID CONCRETE BUILDING IN SITÚ ABOVE LOW WATER LEVEL

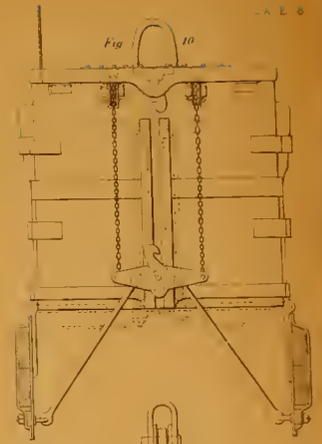
Scale for Figs 1 2 5 & 5

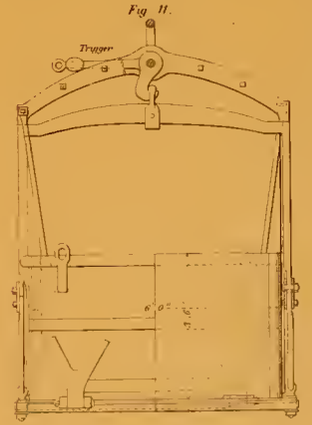
Scale for Figs 6 & 7

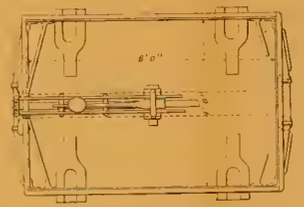




SKIP
USED FOR DEPOSITING 16-TON BAGS OF CONCRETE







SKIP
USED FOR DEPOSITING 5-TON BAGS OF CONCRETE

Scale for Figs 8 9 10 11 & 12

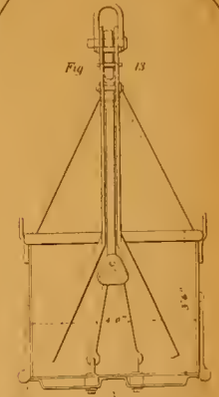
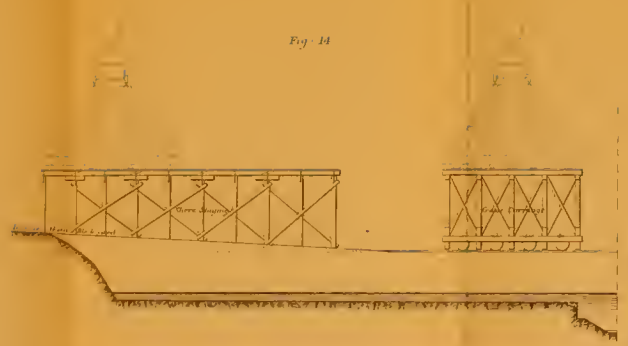
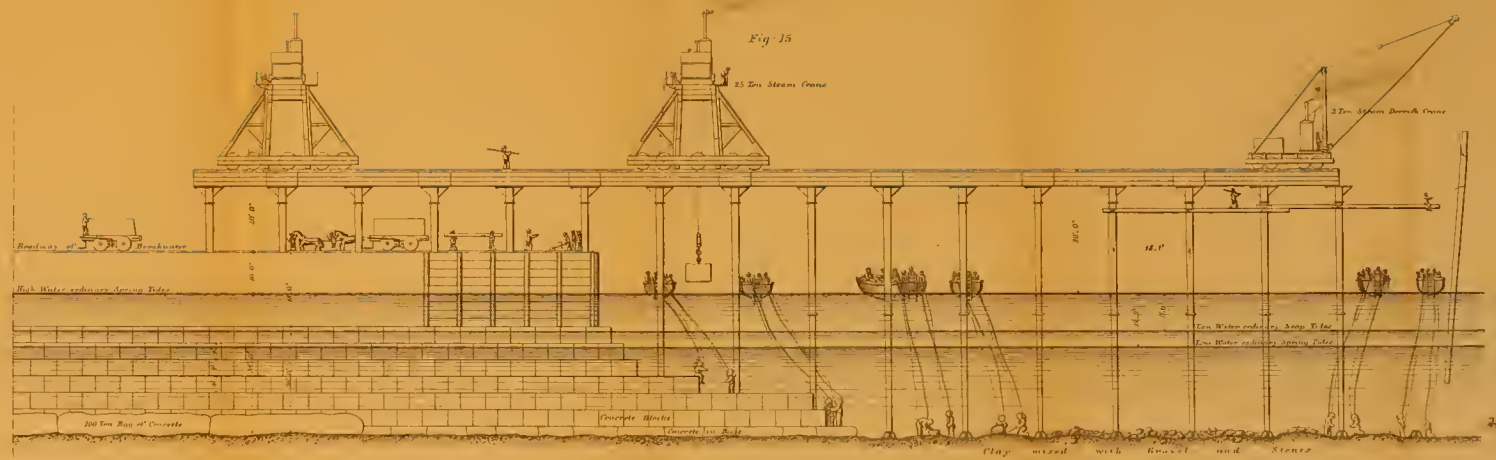


Fig. 14



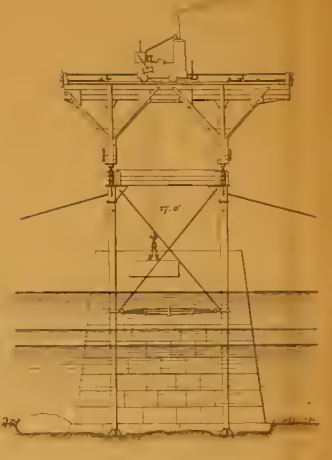
LONGITUDINAL ELEVATION OF SHORE STAGING AND CRANE CARRIAGE.

Fig. 15


25 Ton Steam Crane
3 Ton Steam Derrick Crane
Roadway of Breakwater
High Water ordinary Spring Tides
100 Ton Rag & Concrete
Concrete Blocks
Concrete Ist Bed
Low Water ordinary Neap Tides
Low Water ordinary Spring Tides
Clay mixed with Gravel and Stones

LONGITUDINAL ELEVATION OF STAGING SHEWING CRANES AND DIVERS AT WORK.

Fig. 16



CROSS SECTION OF STAGING.

Scale 24 Feet = 1 Inch.

0 5 8 10 15 20 25 30 40 50 100 150 Feet.

KUSTENDJIE SOUTH JETTY.

Fig 1
CROSS SECTION OF JETTY
shewing Gantry and mode of lowering the Blocks.

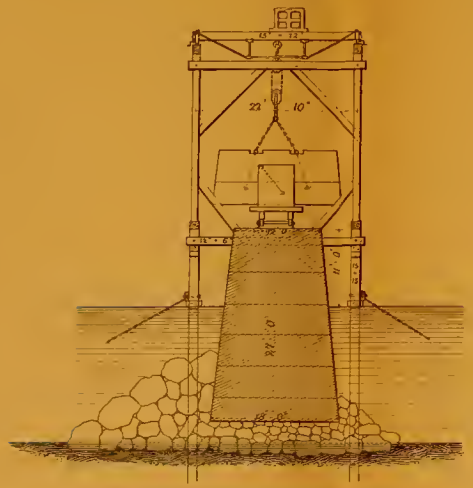


Fig 2
LONGITUDINAL SECTION OF JETTY & ELEVATION OF GANTRY.

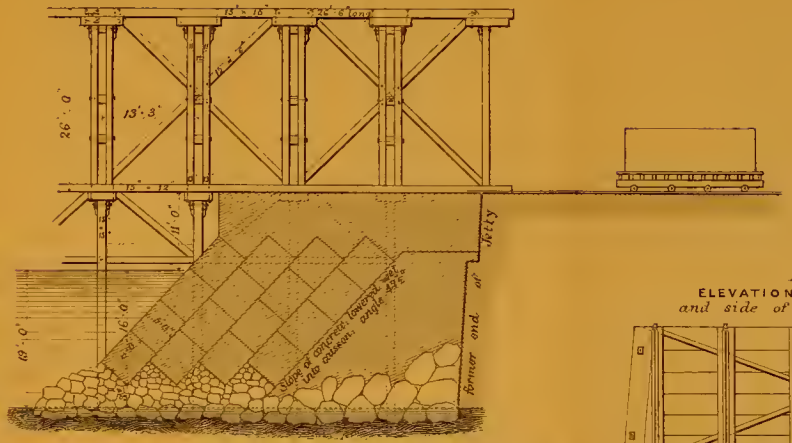

26' 0"
13' 3"
16' 0"
19' 10"
Slope of concrete blocks 1 to 1
Slope of concrete blocks lowered with adhesion angle 45°
former end of Jetty

Fig 3.
PLAN AT TROLLY LEVEL
shewing space for blocks to swing round.

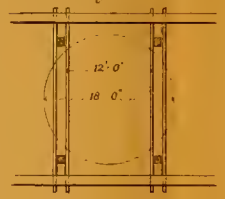


Fig. 4
PLAN OF TOP OF GANTRY.

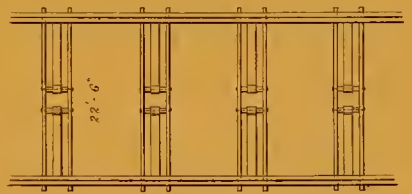


Fig. 8.

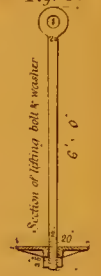


Fig. 5.
ELEVATION OF TROLLY
and side of moulding Boxes

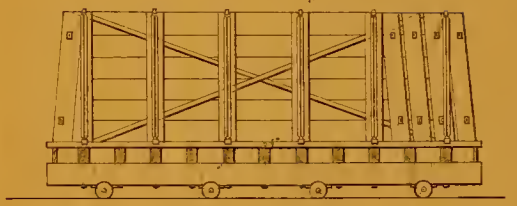


Fig. 7.
END VIEW OF BOXES

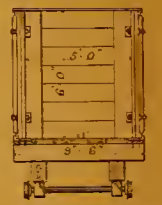


Fig. 6.
PLAN OF BOTTOM OF MOULDING BOXES.
6" batter at each end

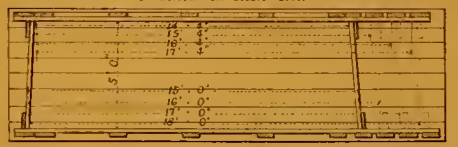
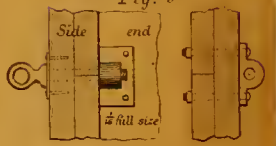


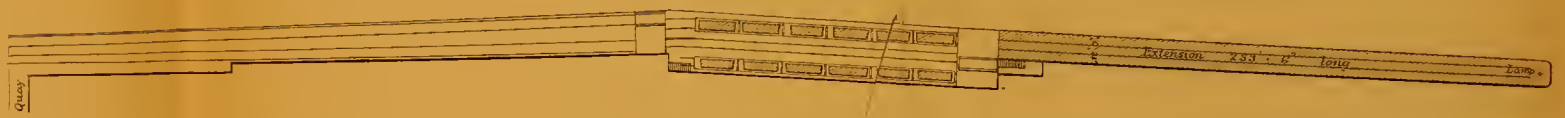
Fig. 9



Scale for Figs 1 to 4.
5 0 5 10 15 20 25 30 35 feet

Scale for Figs 5, 6 & 7
5 4 3 2 1 0 5 feet

Fig. 10.
PLAN OF JETTY.



Scale for Fig. 10.
10 0 10 20 30 40 50 100 Feet

CYLINDER FOUNDATIONS.

SCINDE, PUNJÁB AND DELHI RAILWAY.

Fig. 4

Fig. 2

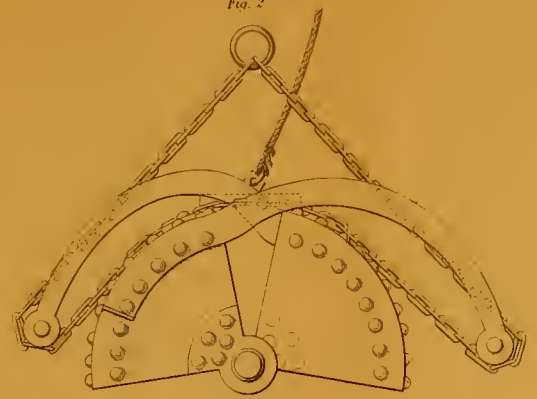


Fig. 1

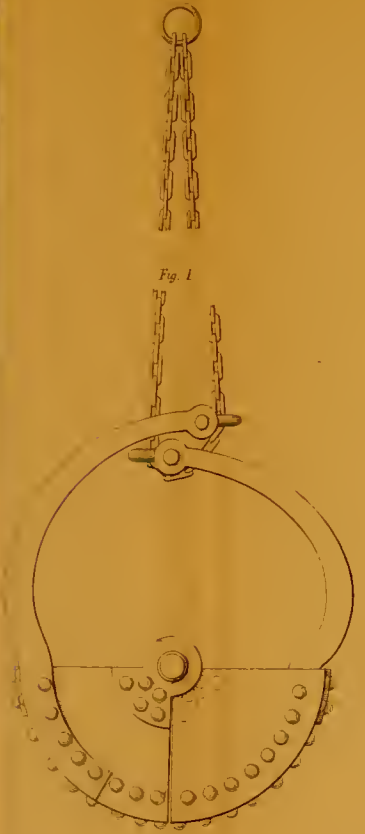
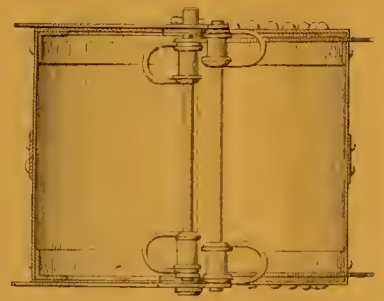


Fig. 3.



BULL'S DREDGER

Fig. 5

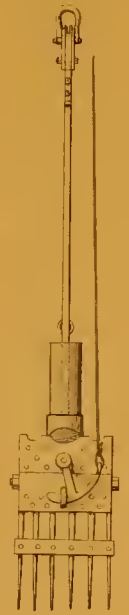


Fig. 6

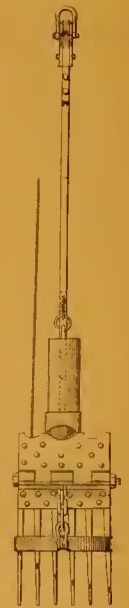


Fig. 7

FOR HARD CLAY

Scale

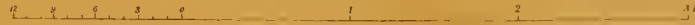


Fig. 8

IVES' EXCAVATOR.

Fig. 9.

FOR SAND.

Fig 1

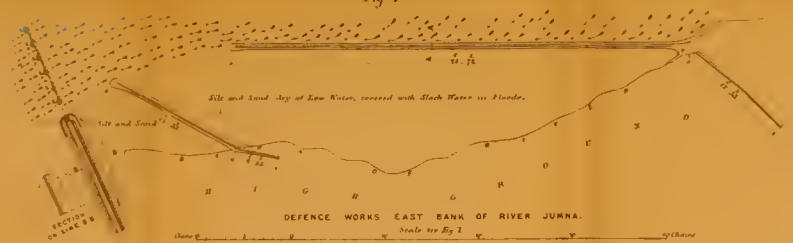

Silt and Sand dry at Low Water, covered with Slack Water in Floods.
Silt and Sand
SECTION ON LINE B B
DEFENCE WORKS EAST BANK OF RIVER JUMNA.
Scale for Fig 1

Fig 2

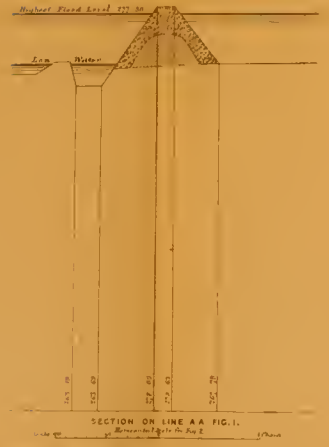


Fig 9

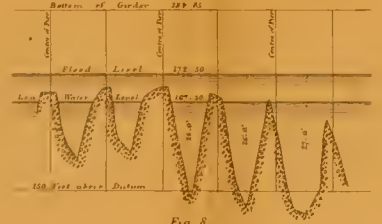
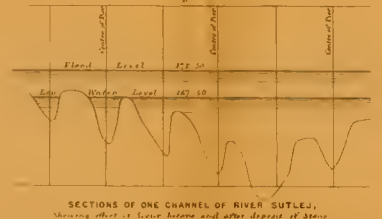


Fig 8



SECTIONS OF ONE CHANNEL OF RIVER SUTLEJ,
Showing effect of Scour before and after deposit of Stone

Fig 3

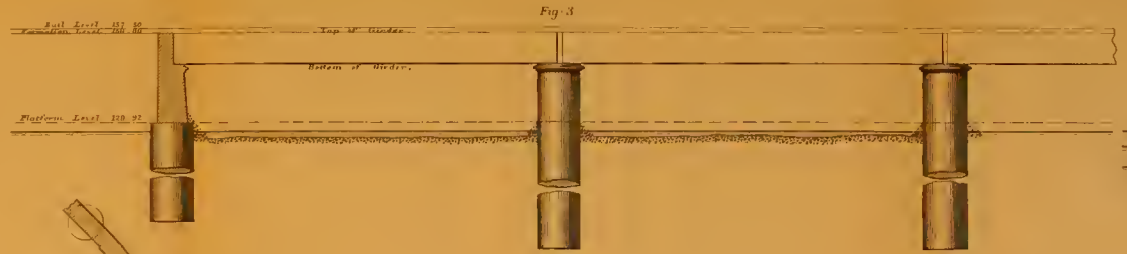


Fig 4

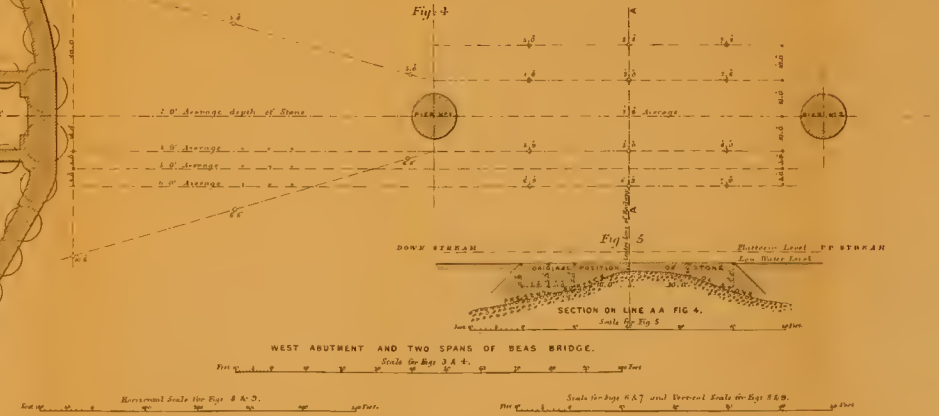


Fig 5

SECTION ON LINE A A FIG 4.
Scale for Fig 5

WEST ABUTMENT AND TWO SPANS OF BEAS BRIDGE.
Scale for Figs 3 & 4.
Horizontal Scale for Figs 6 & 9.
Scale for Figs 6 & 7 and Vertical Scale for Figs 8 & 9.

Fig 6

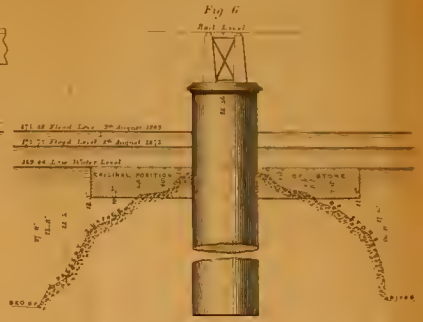
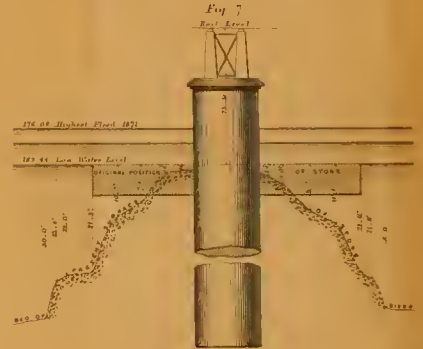


Fig 7



TWO PIERS OF SUTLEJ BRIDGE.
Showing position of stone before and after Floods

1939
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